Tektronix
Restorer's Notebook

by Giovanni Becattini

An illustrated guide to classic oscilloscopes restoration and preservation

Restoring classical oscilloscopes is an exciting activity, in my opinion, or a thoughtless way of wasting time and money, according to someone else.

In most of the cases, however, these oscilloscopes can be repaired, because an excellent documentation is available, many spare parts can be found rather easily, and there are many Internet groups and videos that can help you.

This e-notebook is mainly intended to support those who are going to restore or simply repair old Tektronix oscilloscopes.

I hope you will find valuable the great amount of information, descriptions, suggestions, technical notes, photos and schematic diagrams. Among them, an almost complete component layout of the original 545 oscilloscope, with relative reference designators, not present in its original manuals.



Giovanni (*Gianni*) **Becattini,** born in Florence, Italy, in 1951, is a graduated electronic engineer and a pioneer entrepreneur.

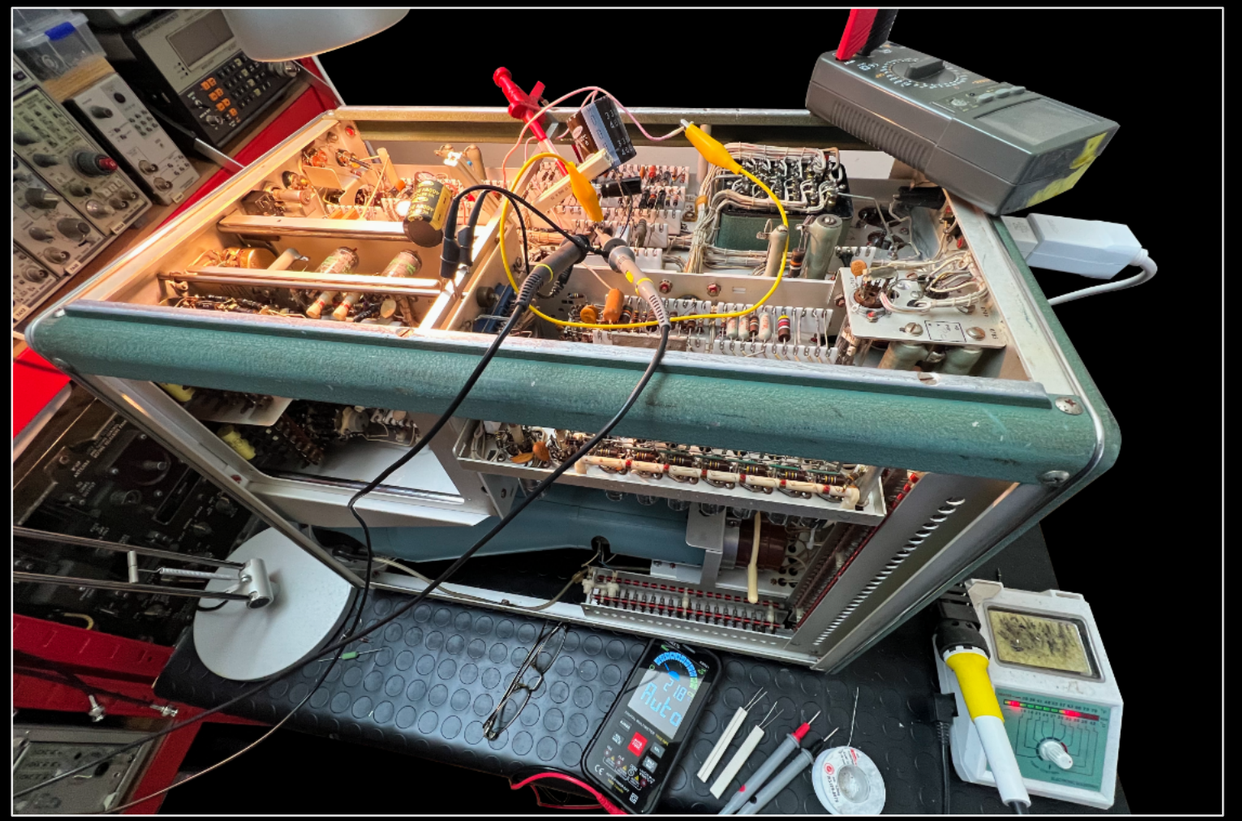
Aged sixteen he started a cooperation with *CQ Elettronica* the most important Italian magazine for amateur electronics. In 1973, he started the design of a computer based on the first 8080 samples available in Italy. In 1975 he presented the first Italian microcomputer project and founded *General Processor* (formerly *Micropi*) the first company in Italy producing computers for personal use. In 1998 he founded *AEP Ticketing Solutions*, today a Modaxo company.

Author of several books and publications, he still holds the role of AEP responsible for innovation, electronic payment systems, hardware products development and quality.

Giovanni Becattini

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Tektronix Addiction



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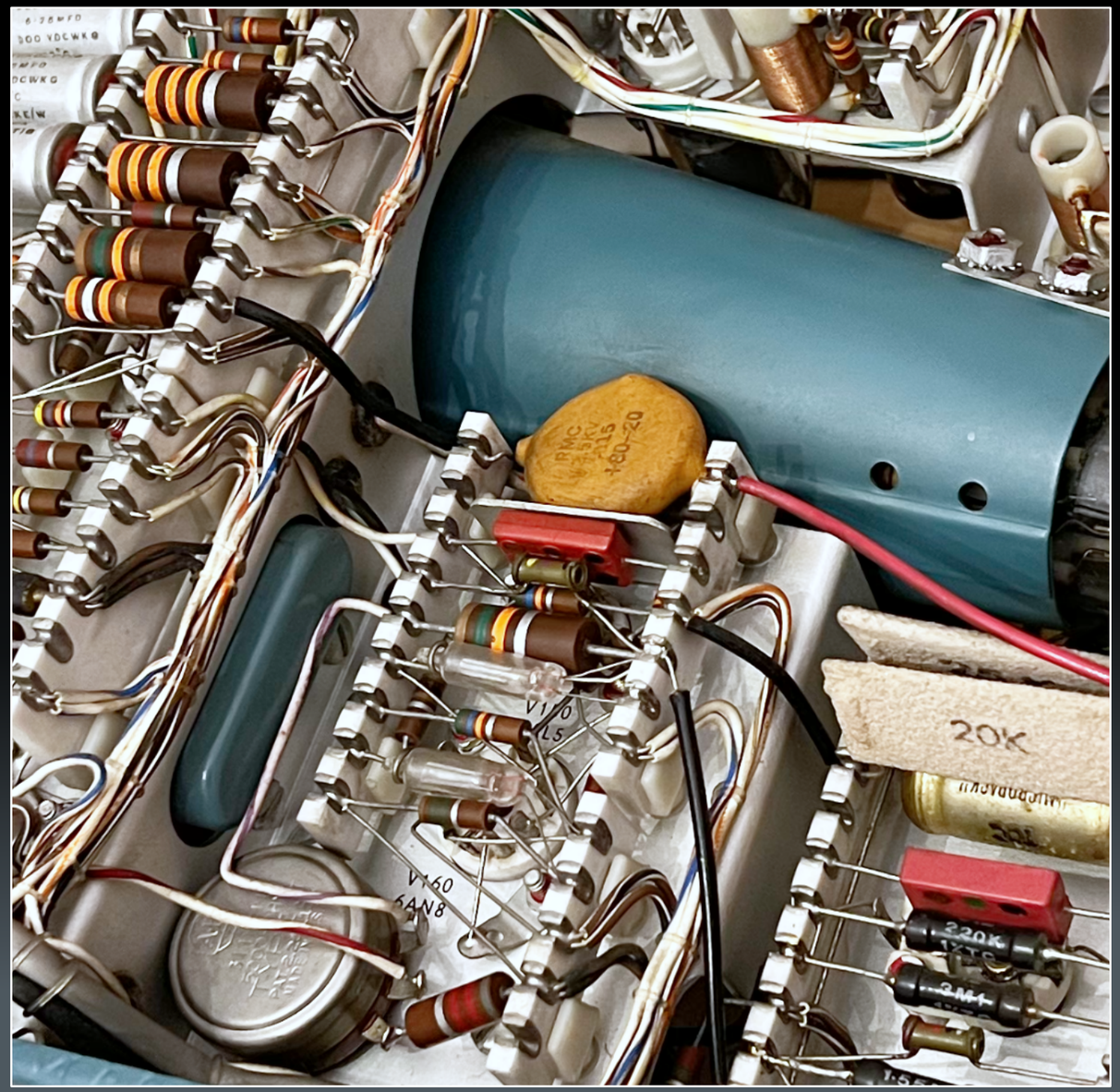
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Why this book

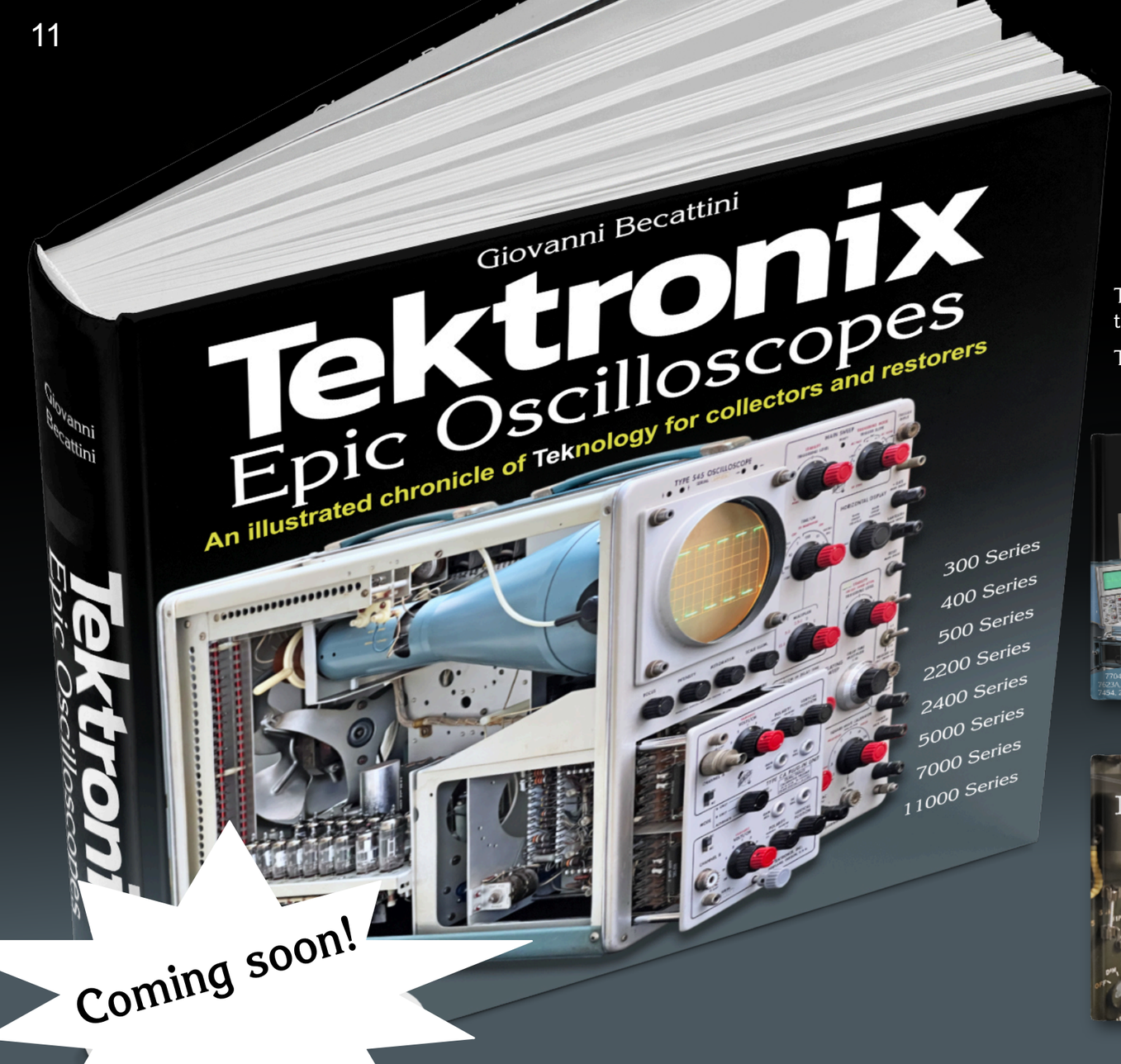
Restoring classical oscilloscopes is an exciting activity, in my opinion, or a thoughtless way of wasting time and money, according to someone else. In most of the cases, however, these oscilloscopes can be restored into operation, because an excellent documentation is available, many spare parts can be found rather easily, and there are many Internet groups and videos that can help you.

This e-notebook is mainly intended to support those who are going to restore or simply repair old Tektronix oscilloscopes. It was created with the aim of concentrating specific technical topics that would have excessively burdened the descriptions contained in my other books, and also of reducing their size, which was overly growing.

I hope you will find valuable the great amount of information, descriptions, suggestions, technical notes, photos and schematic diagrams. Among them, an almost complete component layout of the original 545 oscilloscope, with relative reference designators, not present in its original manuals.

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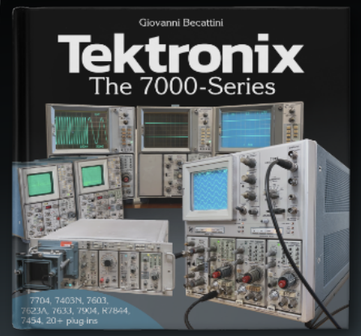
To my wife
and my family



Classic Equipment Library

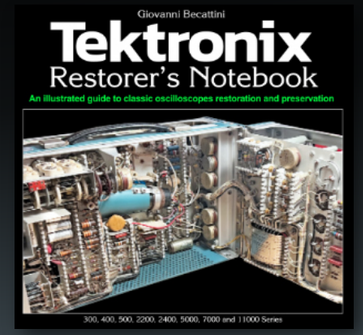
This book is part of the collection dedicated to classic electronic equipment. The most important among them it is the coming soon *Tektronix Epic Oscilloscopes*.

The others are currently all free e-books, which you can download from my web page.



Tektronix, the 7000 Series

A 750-pages in-depth look at the most classical Tektronix 7000-Series oscilloscopes: models, technologies and restoration techniques.



Tektronix Restorer's Notebook

A valuable help for the vintage oscilloscopes restorer, with repair stories and component layouts for some classic equipment.

(in preparation)



Military surplus equipment

A 164-pages review of more than 30 famous military receivers, transmitters and instruments, with tons of beautiful photos.



The great Hewlett-Packard

A 550-pages review of many classical instruments from the fifties to the nineties by the great Hewlett-Packard: spectrum analyzers, oscilloscopes, voltmeters, frequency meter, up to the handheld calculators and the Series-80 computers.



WARNING!

Very dangerous voltages exist inside every oscilloscope, even after it is switched off.

All the technical information contained in this book is intended for EXPERT TECHNICIANS only, fully aware of the connected risks and their management.

If you are not an expert, don't try even to open them under any circumstance, and always refer to the applicable documentation for their use.

Tektronix Restorer's Notebook

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All Models

Hints and tips

In these pages you can find hints, descriptions and suggestion on miscellaneous topics related to Tektronix oscilloscopes' repair and restoration.

Restoring a Tek

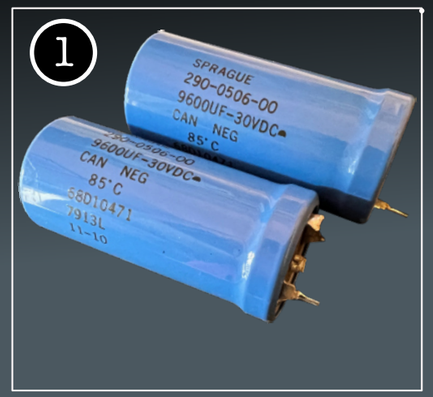
If someone, like me, has something wrong in his head, can find that restoring an old Tektronix scope can be a can an exciting activity. In most of the cases, they can be repaired, because an excellent documentation is available, many spare parts can be found rather easily, and there are many groups and videos that can help you.

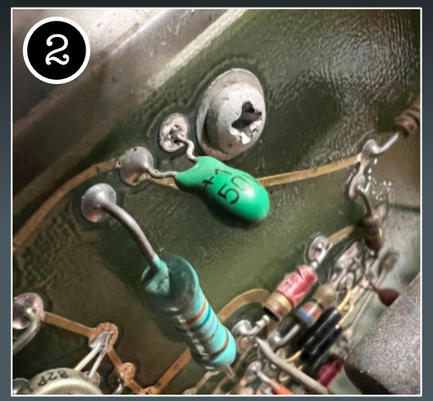
Components were, in general, of high quality. Apart from transistor or ICs, the most common faults are the large electrolytic capacitors in the power supply section, that don't become shorted or explode, but just lose all their capacity. Also the Tantalum capacitors, that in Italian are called "drop shaped", often require to be replaced (they may short and explode, instead).

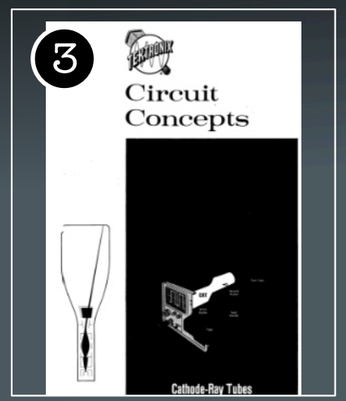
It is surprising, for today standards, that they used sockets almost for any semiconductor devices or relays in their boards. It is even more surprising that these sockets are still reliable, if used with a minimum care. They are very useful in locating faults: if you don't want to squeeze your brain to find the wrong transistor, just check all the transistors with a multimeter.

Another frequent cause of problems are the switches, but cleaning them is often enough. See at page 48 for some tips regarding their cleaning.

It must be noted that Tektronix, as a true leader should do, produced also a lot of books to broadcast its technology to the world. Many of them are still today very interesting and worth of reading.







❶ These electrolytic capacitors have lost almost all their capacity and were substituted with modern ones in a 7603 oscilloscope. ❷ One of the feared Tantalum capacitors. When they get shorted, can produce more important damages.
❸ One of the books of the Tektronix series, where their technology gets open to the world.
❹ A typical board of a 7000-Series scilloscope. Note the sockets for the ICs and transistors.
❺ The detail of an almost invisible transistor socket. If you don't know, you can't see them!



Tektronix Colors

The Tektronix blue is very peculiar and does not correspond to any RAL color. I am even not sure that the color has been always the same and that did not change in all these years. I suspect that the old equipment was darker and the newer is lighter. My opinion is based on what I could see in the units I have, but maybe also that the color changed simply in consequence of age.

Some of the my units were so badly reduced that I felt myself forced at least to try to repaint them. What I could do was to get a cabinet in a rather good state (465) and go to a shop specialized for painting, asking them for a special color.

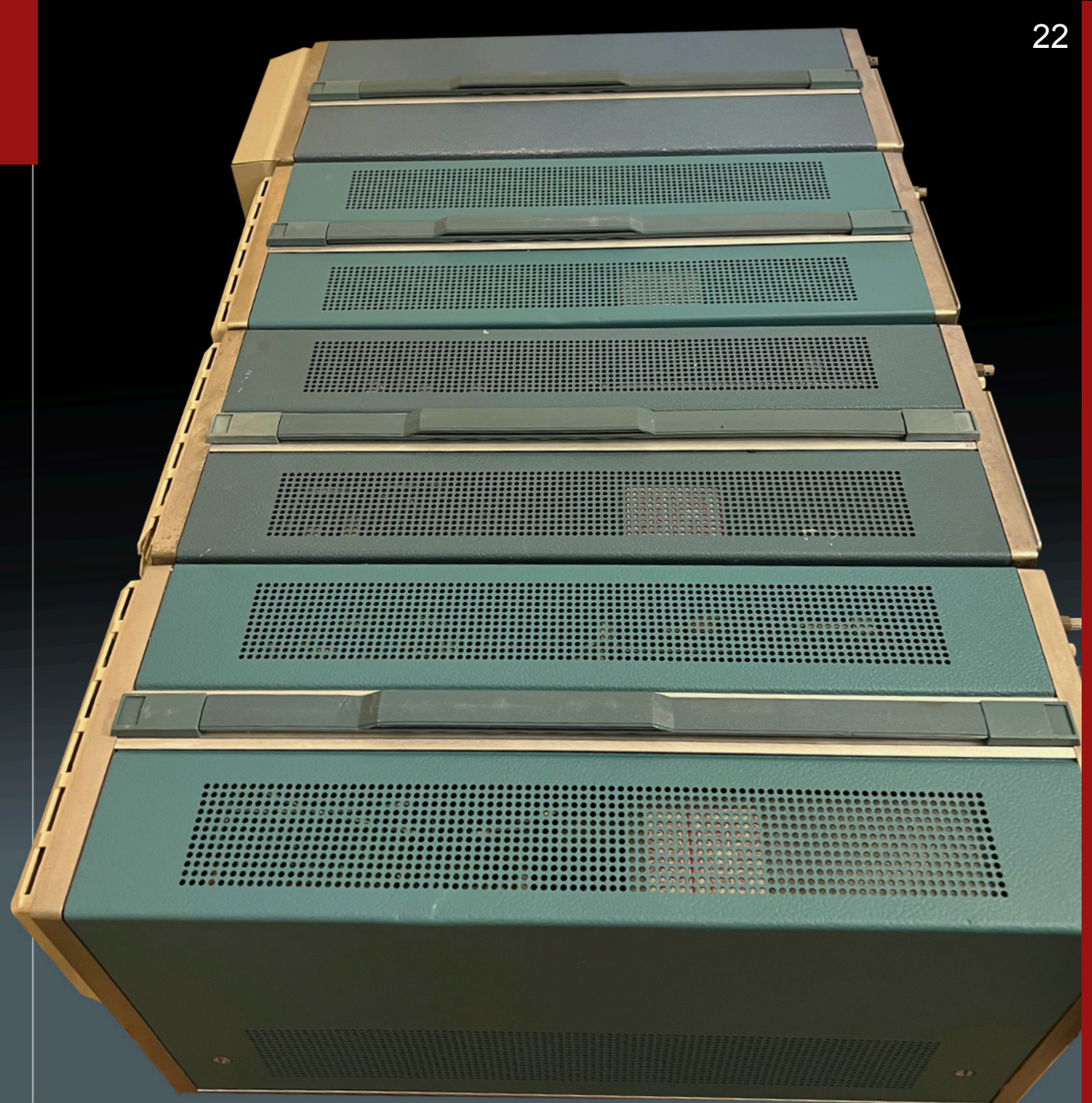
They were very intrigued: nobody asked them a paint for an oscilloscope! At the end they produced a color that was not perfect but rather near to the target I wanted. The cost was not so little (more than 50 euros for 1kg), but the painting is really good quality, much better of any spray.

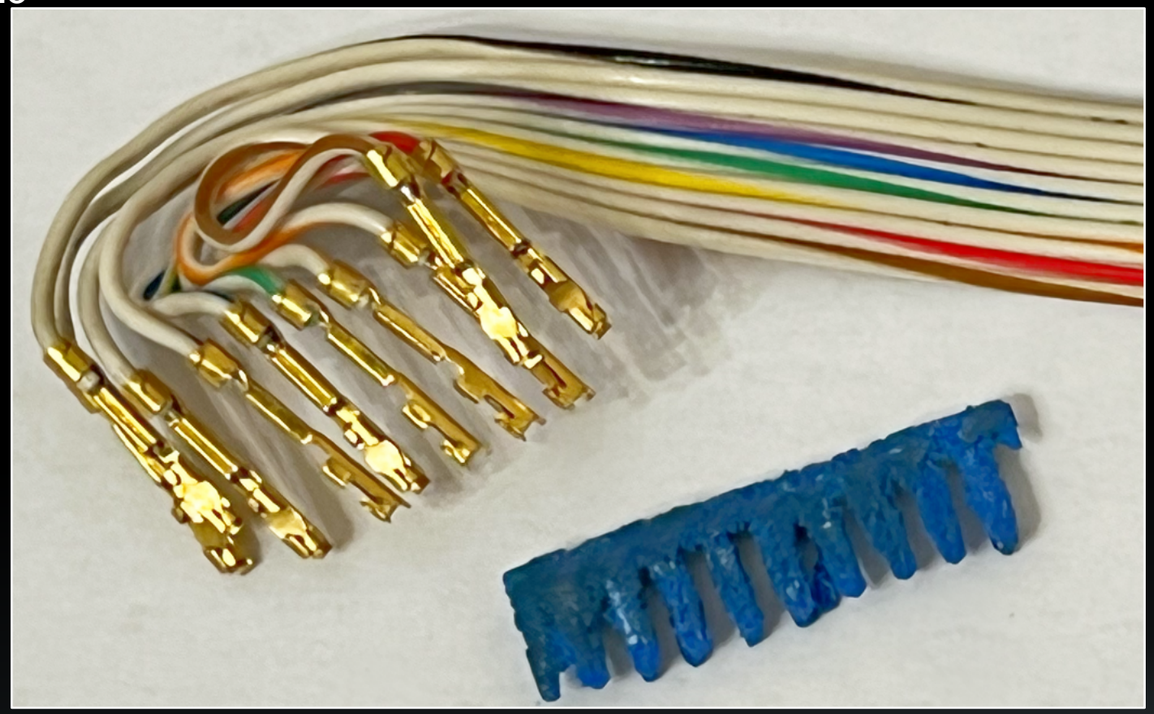
Should it interest someone, the paint code is Sikkens Rubbol BL Magura Q4.20.38 5051.

In the photo on the right: the darker ones are the original, the lighter ones are the covers repainted by me.









The knobs also?

In this picture you can see the color difference between the TIME/DIV knobs of a 7B53, one from a clearly worn by use, the other that probably spent its life in a box.

The UV-rays effect on plastics is very strong, as the restorers of ancient computers well know (photo on the right).





Plastics Colors

In my professional life I had the opportunity to collide with plastics. I admit that at first I thought that the matter was easier than it actually is. Just like electronics, plastics also require a lot of technology and experience. A mold for plastic is generally a very large, heavy and complex object and its design must take into account a large number of factors, such as the ability of the material to flow even in the most extreme angles, temperatures, deformations and much more.

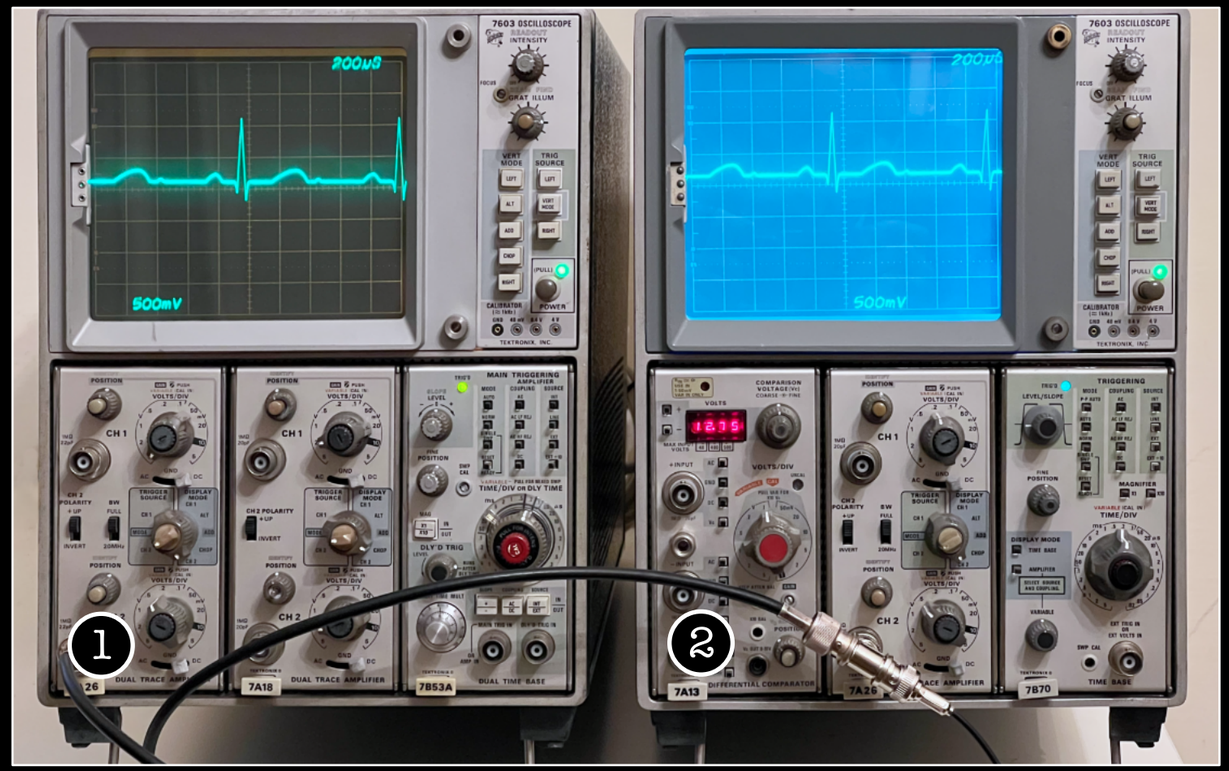
Not everyone knows that also the color has a big part in the result. Years ago, we introduced a new product, very important for our company. It was designed by a very famous industrial designer and we developed for it a very tough test plan, to avoid problems in the first units that were going to hit the market. One of its key points was a beautiful glass in the front, glued to the plastic with a super technological adhesive, subject of deep testing. Well: after few days we received complaints about the glass falling apart… We suspected everything: the production process, the temperature, the humidity etc. But in the end we discovered that the cause was… the color! All the tests had been performed with yellow plastic, while the production was in green. It was obtained with a pigment, added to the raw material, not compatible with the adhesive. Still today, while I am writing these notes, I am fighting against the problem of the EN 45545-2 certification (about the safety of the railway sector) of an orange color, that is not present in the black.

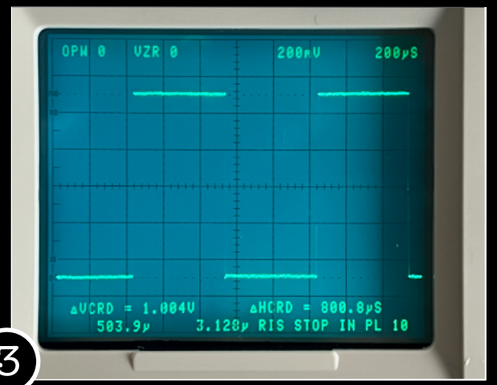
All this to say that perhaps also Tektronix had a problem like that. My R7844 S/N B010112 is probably the 12th unit produced, but, as you can see from the photos, is still today in good shape. So I was surprised when I found some blue plastic debris in the box. Eventually, I found its origin: two connectors of a flat connecting the Readout board. Both connectors were almost totally corroded and crumble. The biggest piece remained is that in the photo here. The other connectors were all good and there was no sign of corrosive liquids. I suspect that the blue plastic pigment caused premature aging of the material (if we can say “premature” after 38 years).

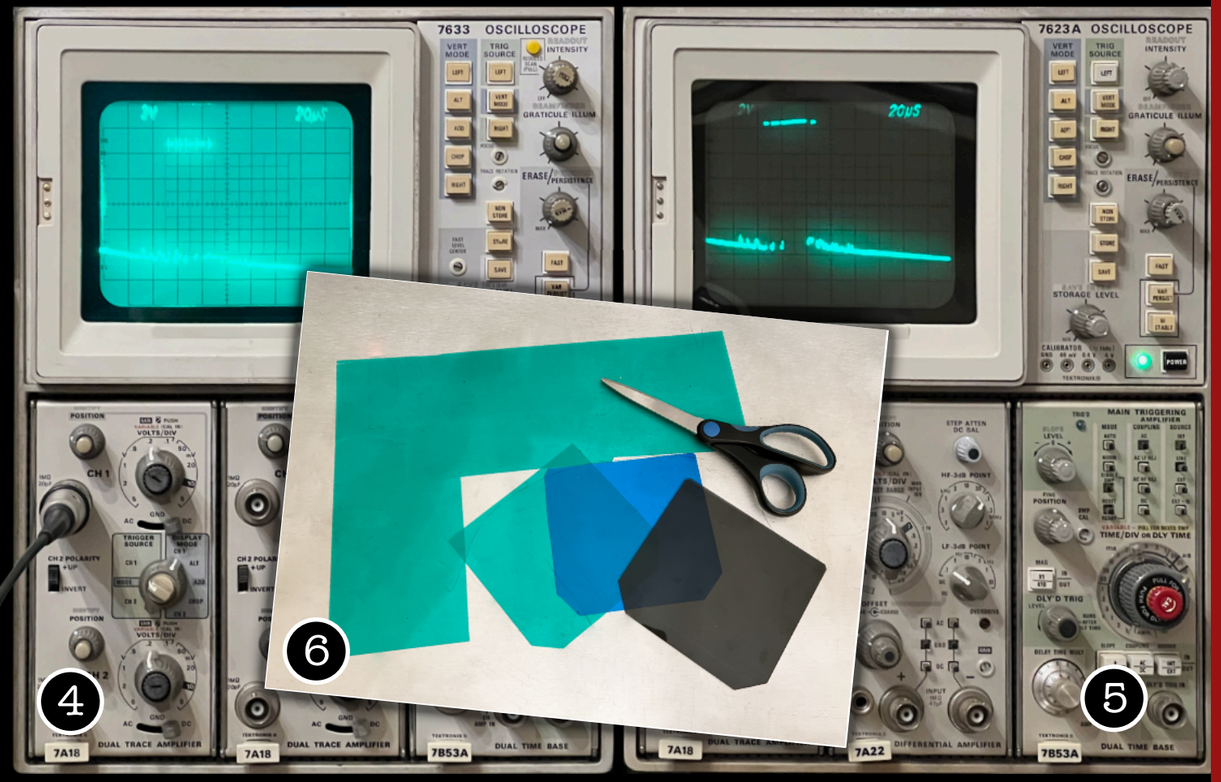
Optical Filters

As for the human beings, the “gaze” characterizes an oscilloscope, and they also use “contact lenses” to modify their look. Which is the best optical filter that we can use to make easier our work? I thought that it depends on the photo camera used, but I discovered that normally the colored filter was removed before taking photos at high writing speed, to increase the light hitting the film (the transparent filter has the implosion protection purpose and is not to be removed). So, it was probably only a matter of taste, and/or of environmental conditions.

Here you can see scopes with different filters: in ❶ is the standard 378-0696-00 filter supplied with the 7603, while in ❷ the optional blue filter 337-1700-01 that I like much more. The green dark original filters, in despite of the photos, are, in my opinion, much more eye-straining. The best, in my taste, is the standard blue filter ❸ of the 7854/7904 etc. In the case of my 7633, that arrived without filter, I was forced to build a new one, buying from Amazon some transparent plastic sheet (❻). I tried with various colors and probably the best is the light green (❹), while the standard, in the 7623A on the right (❺) is again too dark and makes harder to watch the details. However, as you can see, if you have to take photos with your smartphone, the worst (dark green) becomes decidedly the best…







Key Labels

If you are going to restore an old 7000-Series oscilloscope, you will learn soon that most of their components are top quality, still after half a century, but some of them were, or are today, very weak. Among them, the labels on the pushbuttons. If you are not very careful, these writings dissolve like snow in the sun, even with light detergents (see the photo below on the left).

So, I find convenient to clean the buttons with a swab, using on the writings just clean water, and then applying a transparent coating, that will protect the characters against wearing and canceling (photo below on the right).

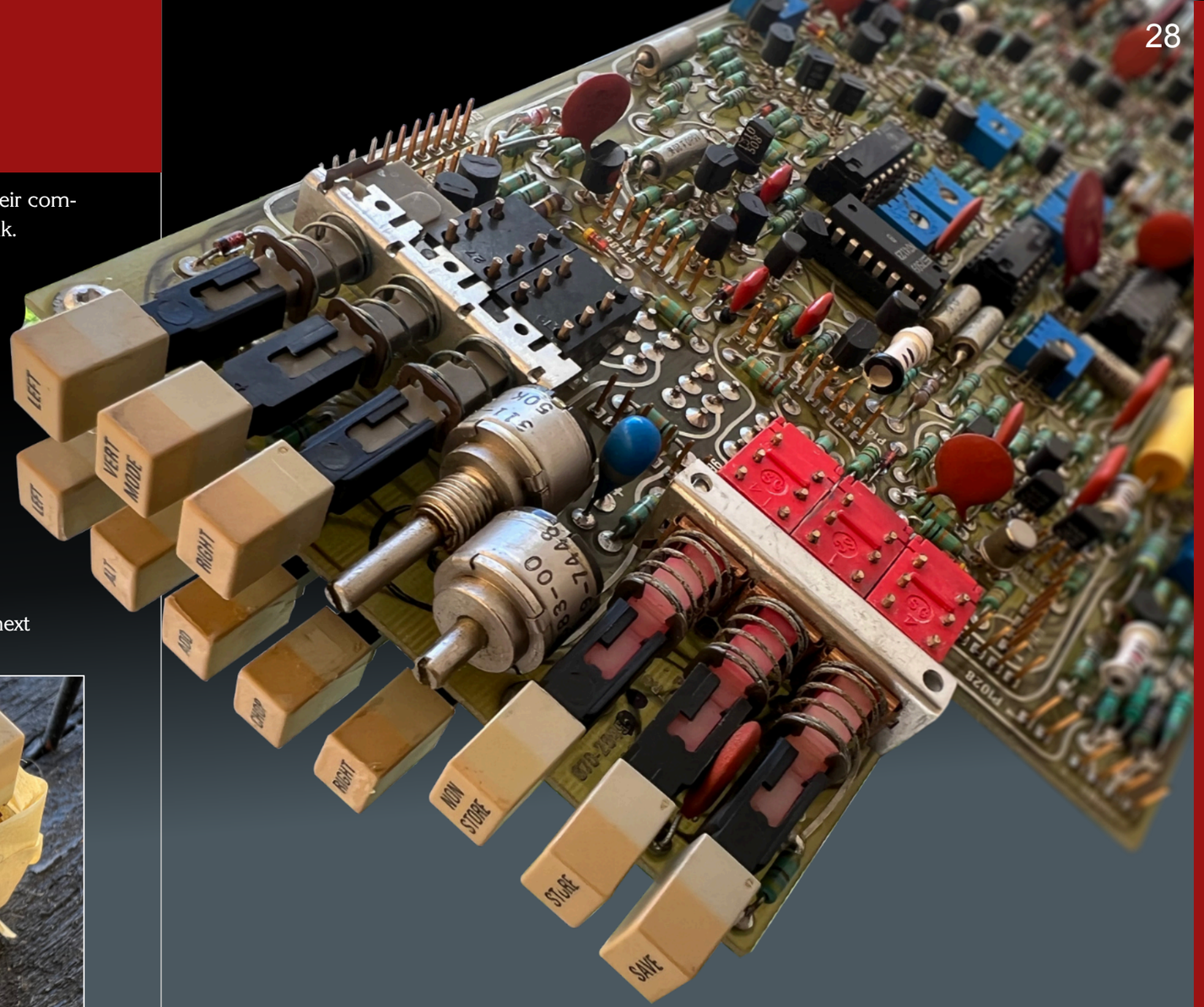
But what can we do when the labels have already been canceled? I have found a possible solution that is not too difficult to put in operation.

First, you need a template. That it is easy, you can download it ready to be printed from my web page (the same where you downloaded this document). If you prefer, you can create them by yourself. I found two different fonts that are very similar to the original one: **BLOGGER SANS MEDIUM** or **UNIVERS CONDENSED**.

I used a waterslide decal paper from Hayes, bought on Amazon, that is reasonably priced. In next pages some extra details.

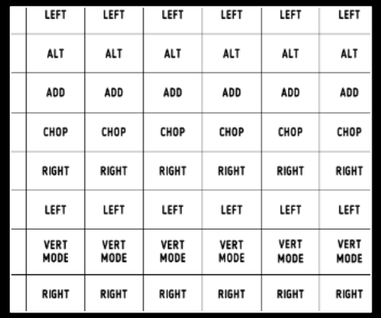








❶ The starting point is a good waterslide decal paper for your printer (laser or inkjet). I used this one from Hayes that is easy to find on Amazon.



LEFT	LEFT	LEFT	LEFT	LEFT	LEFT
ALT	ALT	ALT	ALT	ALT	ALT
ADD	ADD	ADD	ADD	ADD	ADD
CHOP	CHOP	CHOP	CHOP	CHOP	CHOP
RIGHT	RIGHT	RIGHT	RIGHT	RIGHT	RIGHT
LEFT	LEFT	LEFT	LEFT	LEFT	LEFT
VERT MODE	VERT MODE	VERT MODE	VERT MODE	VERT MODE	VERT MODE
RIGHT	RIGHT	RIGHT	RIGHT	RIGHT	RIGHT

❷ You need a template: you can create it yourself or use that I prepared (can be downloaded from the web page of this book). Print it on the special paper.



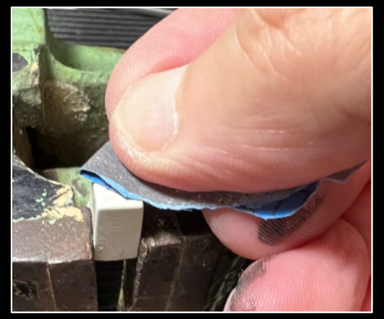
❸ This is a sample starting point. Yellowed keys and damaged labels.d. The yellow is from the old protective coating, not of the key plastic, good indeed.



❹ Removing the keys is easy and require only a pair of pliers. Just grab them gently and pull pull outwards.



❺ Now you need to clean the keys from the old coating. I use nitro diluent, carefully and quickly because is very aggressive toward plastics.



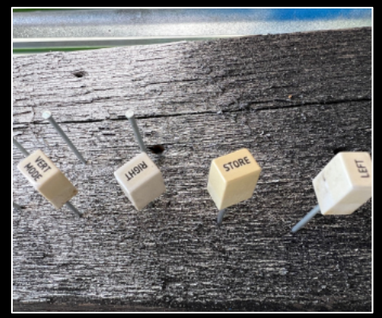
❻ I suggest to complete the work with a pass of very fine sandpaper, that helps to get a perfect surface for applying the waterslide decal.



❼ Now cut the waterslide decal and put it in the water. They say 30-60 seconds, but being the decals small, few seconds are normally enough.



❽ When the decal is ready, gently help it to slide from the paper support to the key and position it correctly. It's simpler than it might seem.

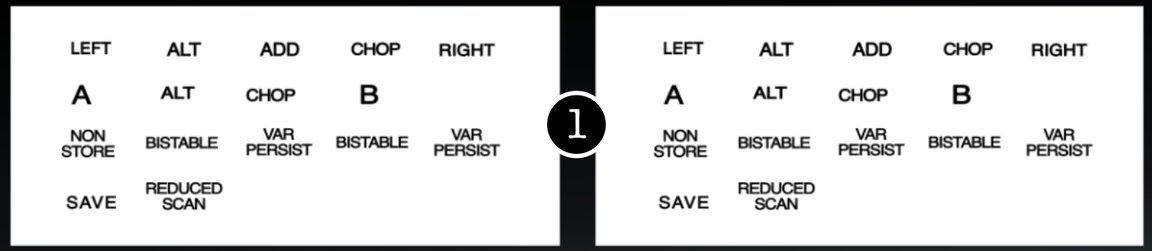


❾ When dry, apply a transparent coating and let the keys dry. Then the keys can be pushed again in their seats. The result is shown on the right.

7834 key labels

The 7834 (and so probably other models) has different keys, compared to the 76x3 we described on the previous pages; many inscriptions have different size, and also the font is different. So the template you can download from my web page is not suitable in this case. You can use the one reported here below; print it in 1:1 scale (100%). The keys became very yellowish, but when cleaned with Nitro-diluent they return to grey. It is very aggressive, so be prudent. I was surprised that the treatment worked also for the knobs, if wisely used. Confirmed by other details, I suspect that the coating is just… nicotine. Probably the 7834 had to endure many years of secondhand smoke. In the front page, the final result of the restoration, compared to the picture below of the original condition.

❶ These pictures can be used to be directly printed on a waterslide decal paper (use 100% enlargement factor). ❷ The keys and the knobs as they where when I purchased the 7834. ❸ The front panel with the renewed keys and cleaned-up knobs.







❷ TESTING A DIODE: it's easy, just check that it does not conduct when reversely polarized (red on cathode), and that, when forward polarized, the cut-in voltage is between 0.2 and 0.9 V.



Semiconductors

Most of us don't have a curve tracer to analyze the characteristics of diodes or transistors, so, the only way that I see to check the active components is the old multimeter, said VOM (volt/ohmmeter).

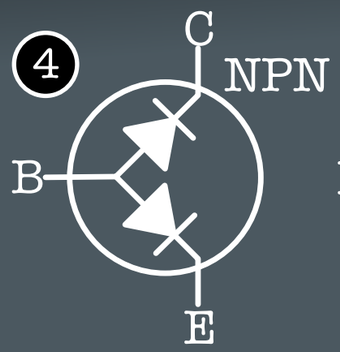
A diode (❸) is an electronic component with two terminals, said cathode and anode, that conducts only in one direction, i.e. when the anode is positive respect to the cathode (direct or forward polarization). When the anode is negative, it does not conducts (reverse polarization). A good diode should have zero resistance in the former case and infinite in the latter. The reality is something different; diodes in the forward direction, for example, need to surpass a threshold voltage, or cut-in voltage, before being able to conduct electricity.

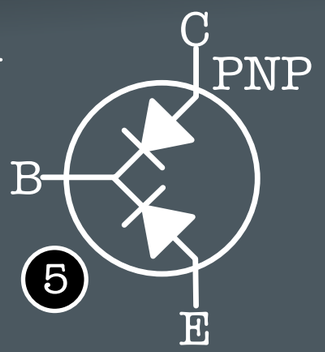
Any VOM (❶) has a function to test diodes, implemented as shown in schematic ❷. You test that the diode does not conducts when reverse polarized and that conducts when forward polarized. In this case the VOM gives you the cut-in value (normally 0.2÷ 0.9V). The test is done with a 3÷4 V battery.

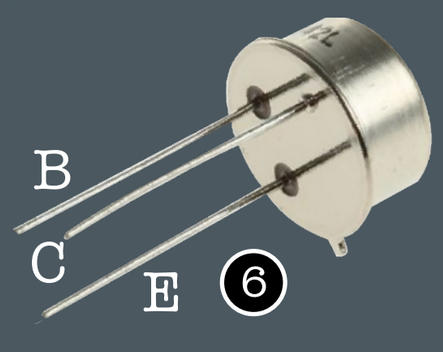
A transistor (❻) can be seen as two diodes combined together (❹ and ❺), so you should test it as two diodes. E.g (for an NPN): red probe on B, conducts toward C and E. Black probe on B, no conduction toward C and E. Test always also that there is no conduction between C and E, in both directions.

Other components soldered to the board can alter the readings. Luckily, most transistor on 7000-Series boards have sockets, so checking them is extremely simplified.

In my whole life, I never tested so many transistor as now that I work on old Tek stuff…







Ripple

Every time that I read something telling “now measure the ripple”, I feel myself uncomfortable, because I normally see a lot of noise, that seems to be independent on the ripple itself.

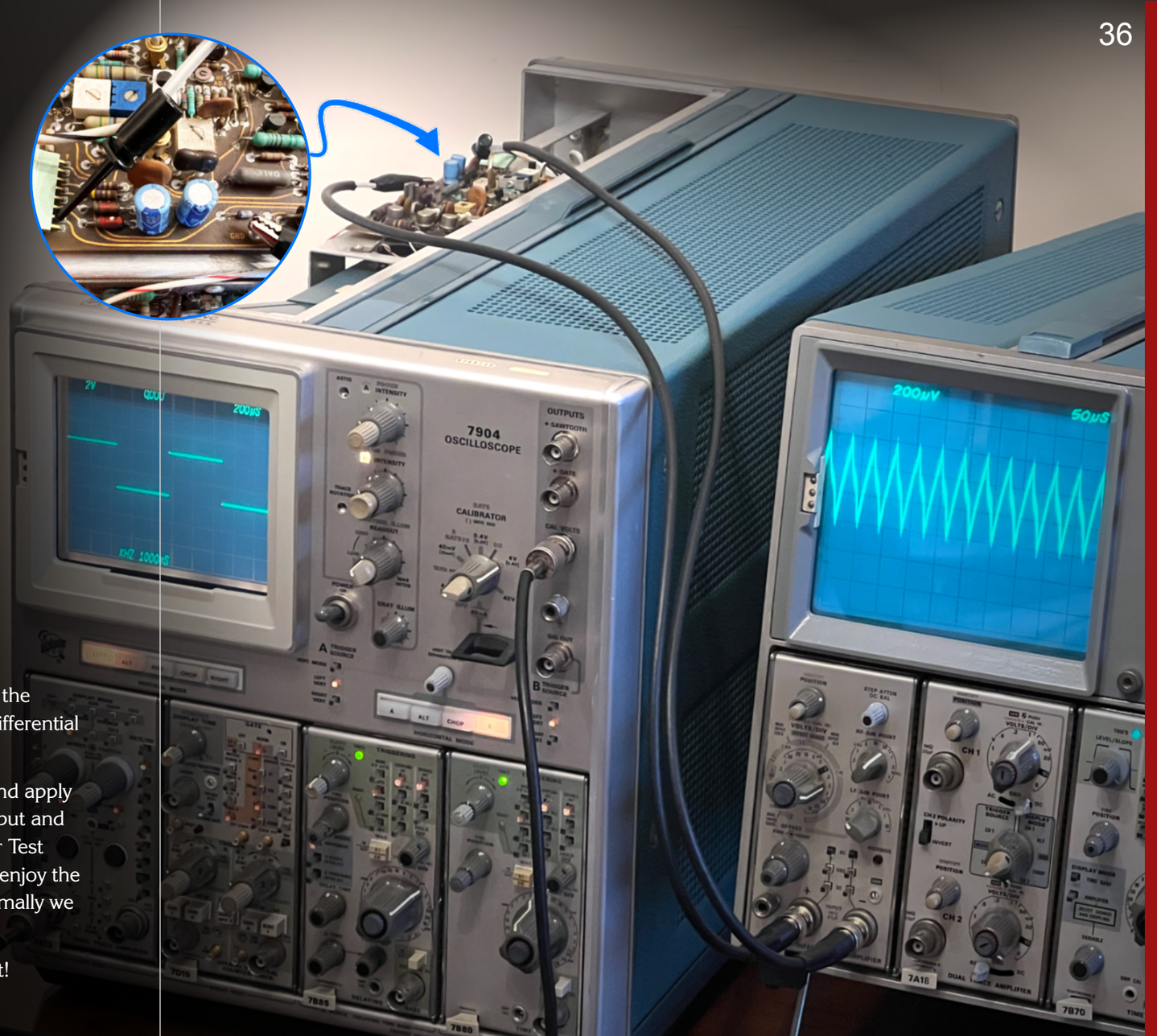
In other respects, measuring the ripple is important when we deal with power supplies, as often happens with Tektronix old stuff. I have not a long experience with them, but for what I learnt in these months, problems with power supply are the most common with that old gear, especially for the “dried” capacitors (I don’t know if really something dries, but it is a convincing expression). I found more than a couple of scopes that were neither starting up, because the filter electrolytics had lost almost 100% of their capacity. But what when you are in the middle of the drying process, i.e. the capacitors are not yet dry but on the road to drying? Normally you get a greater ripple, that can produce dysfunctions.

A sign of that is given by readout characters that begin to “dance”. Initially, I though that it was some timing problem in the Readout board, but I was wrong: in the 7000-Series, there is no raster, like in a television; if the character positions are unstable, they move accordingly the changing voltage on the screen. If the ripple affects the horizontal and vertical amplifier as well, the effect is that the characters slightly move horizontally and vertically, producing that funny and hated effect. I tried to correct locally the +130V ripple on the horizontal amplifier (adding a capacitor), and character continued oscillating only vertically. But adding capacitors locally is not a good solution, we must go to the root of the problem.

I found a Tektronix technical note specifying the allowed ripple for 7904, 7844 etc. and it is in the 1÷2 mV order. How can I measure that? The article in some way tells also the answer: use a differential vertical amplifier. So I tried with the 7A22 and… wonder, it works!

Just do so: get a BNC/BNC cable, cut it exactly in the middle (to have two identical cables), and apply some form of clip at the free end, forgetting the screen. Now connect one cable at the “+” input and the other at the “-”. Connect one of them on the other side to the ground of the Device Under Test (DUT) and the other on the voltage terminal you want to check. Put both channels in AC and enjoy the neat screen. Generally, is better if you limit the amplifier bandwidth with the relative knob, normally we are not interested in the high frequency noise.

In the photo: a 7603 checks the ripple to a 7904. Look at the marvelous 200uV in the readout!



Hz, Fans & Noise

Looking at many equipment labels, I often asked myself: “why 400 Hz?” 400 Hz power networks have become the standard for weapon systems, aerospace, and aircraft industries across the world, because the 400 Hz equipment is lightweight, reliable, and offers high power capability. As a consequence of it, airports, hangars, and ships that carry aircrafts have 400 Hz power systems.

Continuing with questions addressed to myself, I noted that some 7000-series oscilloscopes have a label stating 50-60Hz, but other have 50-440 Hz (photo below). Why, considered that their power supply are almost identical?

The reply came reading the 7844 oscilloscope description in Tekscope 6-1974:

> Because the 7844 has a DC fan it will operate from a power line having a frequency from 48 Hz to 440 Hz.

So I checked my electronic friends: limited to 60 Hz are those with the fan! The fan is the limiting factor, because often, when present, the fan is based on a synchronous motor, in which the rotation of the shaft is synchronized with the frequency of the a.c. supply voltage. These inexpensive and durable devices can accept the 50 or 60 Hz, but are not able to work at 440 Hz.

I said durable, and they seem to be so, but the fan of my 7633 had start becoming a little noisy, so I dismounted it, as shown here. The fan ball bearings are sealed, and it is not possible to overhaul them. So I limited cleaning up everything and applying some oil drops. The result is good and the noise disappeared. Not too bad, for a motor that has probably been running for tens of years.







The sound of silence

All the 7000-Series mainframes eat energy and produce a certain amount of heat, that must be in someway wasted. All their power supply are of the linear type, even if preceded, in some cases, by a more efficient high frequency inverter, instead of the traditional a.c. mains transformer.

So, all the extra energy must be wasted in heat. The first models, 7704, 7904 and 7603 rely only on natural air flow, while others have a fan, that, as we sow before, can be DC or AC powered.

The fan is something that long time ago was considered mandatory: I still remember the strong blow that you heard near any computer installations.

But the fan noise is really annoying, and when switch it off, you cannot help to think “finally!”. So I tried an empirical evaluation of the noise produced by some oscilloscopes, using an app of the many you can find for any smartphone (50cm distant, front side). The results are summarized in the table below, where you can see that the most modern are the most noisy.

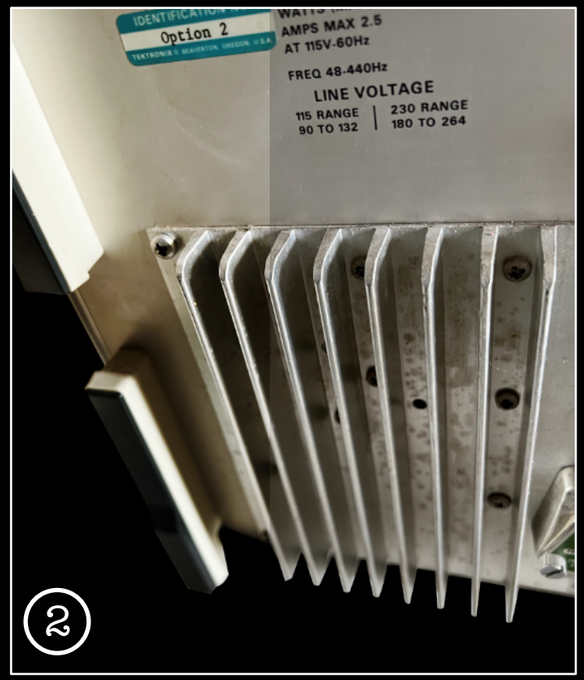
Worth to mention, the 11400-Series, that have an automatic fan speed control, to adapt it to the effective heat production, like any modern laptop do.

Edition 5: other models from other series have been added.

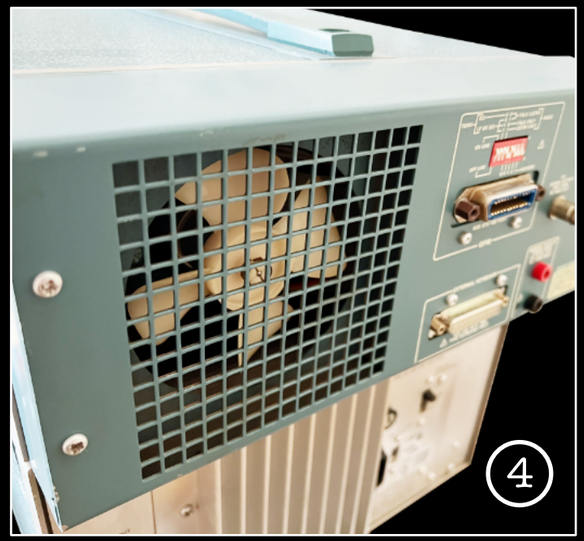


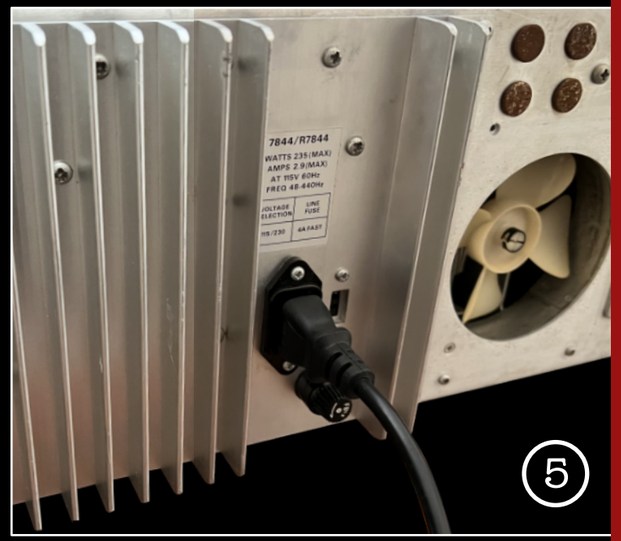
❶ The 7603 is the most elegant: no fan and very slim heat sink, barely visible. ❷ The 7903 succeeds remaining fan-less, but has a large heatsink. ❸ The ugly fan cover of the 7623/7633. ❹ The 7854 fan protrusion is the biggest, but it contains many other circuits. ❺ The 7844 uses both, natural and forced air flow, but it is …justified, having packed almost two 7904 in a volume less than a standard 7904.

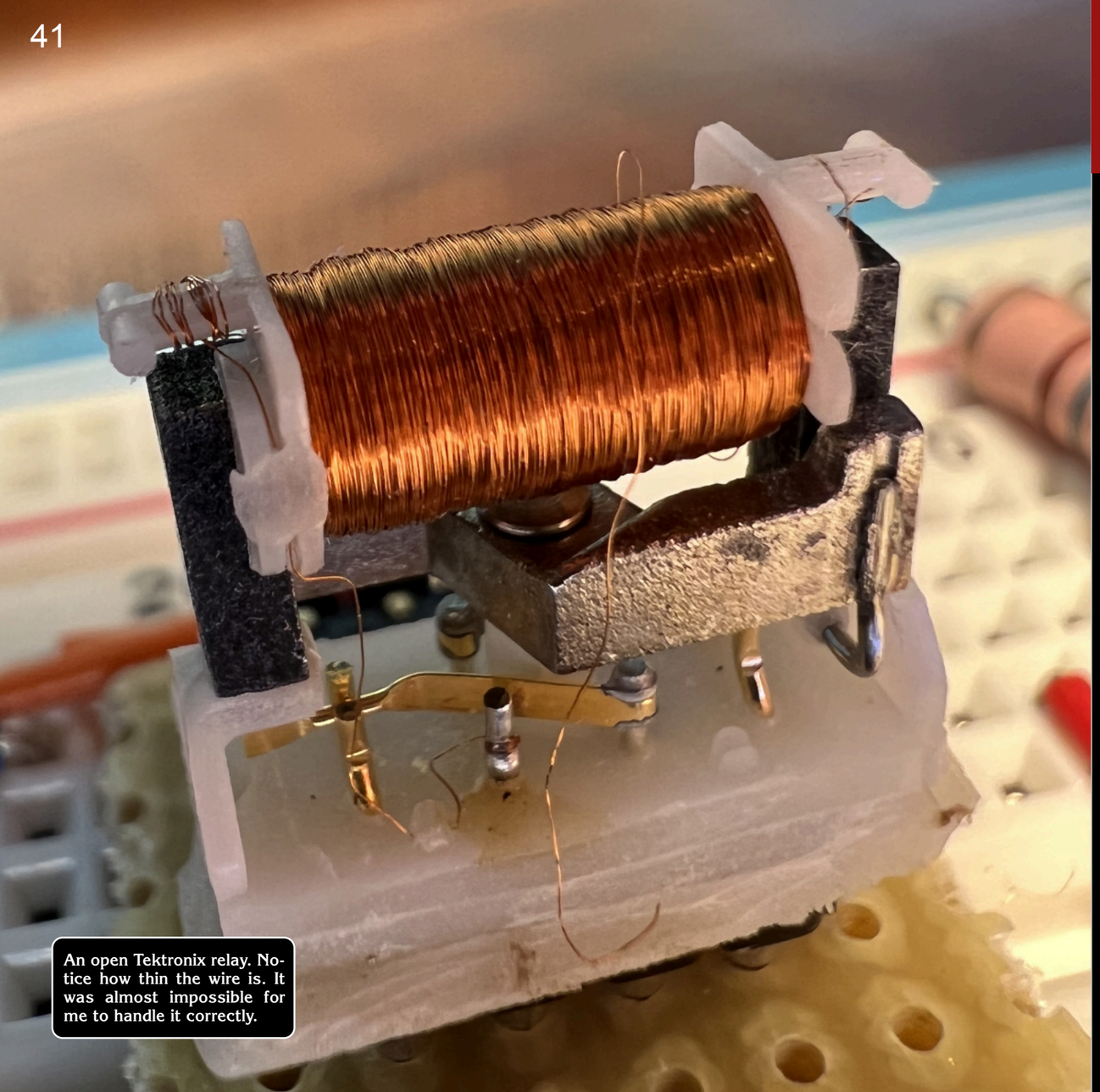
Model	dB 50 cm	Model	dB 50 cm
7704	0	7854	13
7904	0	HP 54502A	19
7603	0	HP 54540A	20
5103N-D11 (5111)	0	2431L	20
7623A	5	2230**	20
7633	5	2430	21
2221**	10	2430A	21
11403*	10	2440	21
7844	12	2465**	25
2445B	12		
* as soon as switched on		** not the original fan	











An open Tektronix relay. Notice how thin the wire is. It was almost impossible for me to handle it correctly.

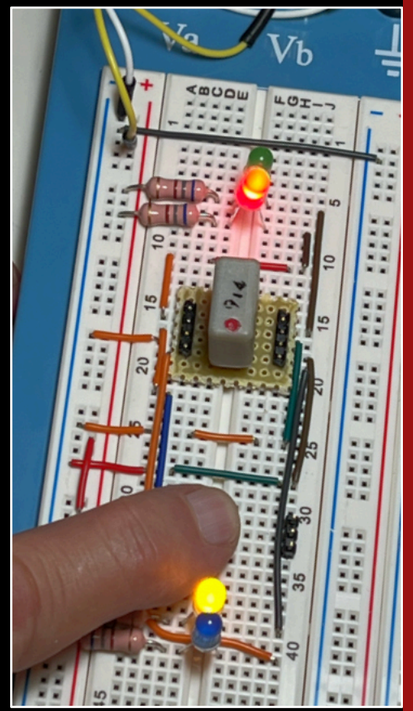
Relays

We introduced the Tektronix relays theme at the beginning of this book, talking about the new solutions of the 7000-Series, describing their benefits and advantages, together with some doubts that we all today have about these old-fashioned components.

Repairing this old stuff, you can discover that, when relays are present, it is likely that possible malfunctions are due to them; but if you think that, after more than forty years, most of them are still in order, we can consider that the Tektronix choice was not so bad. As we noted, Tektronix relays are furthermore very well designed: small, fast and reliable. Most of them, thanks to a very intelligent pin assignment, can also be reversed, i.e. inserted at 0 or 180°.

But how can we manage them today, considering that it is rather difficult to find spare parts? On TekWiki (search “miniature relays”) you can find many articles about their reparation/substitution. I can give here some suggestions, based on my experience.

- Build a relay tester like that in the photo. It is very easy and allows you to quickly understand if a relay is good or less;
- The relay tester works not only as a tester but also as an… healing device. I had two cases where a faulty relay started to work after having exercised it on the tester. This medicine is better if you connect the tester to a signal generator and allow it to run at about 7-8 Hz for a couple of hours. Sometime it happens that a relay works well with the LEDs, but not with the weak signal currents. Often, with this treatment, it can be recovered.
- It is possible (but not easy) to build a new relay capable to fit in the existing sockets, when you have room enough.
- Sometimes, you can transplant a relay of a less important function to other purposes. For example, with 7A13, you can use the S480/490 relays, used for bandwidth limit, to replace S47, 48, 6, 26, 7 or 27.

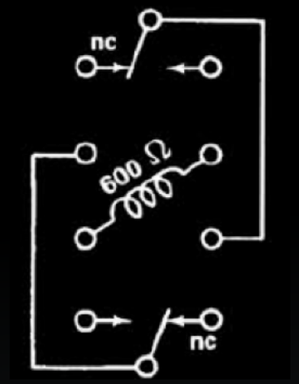


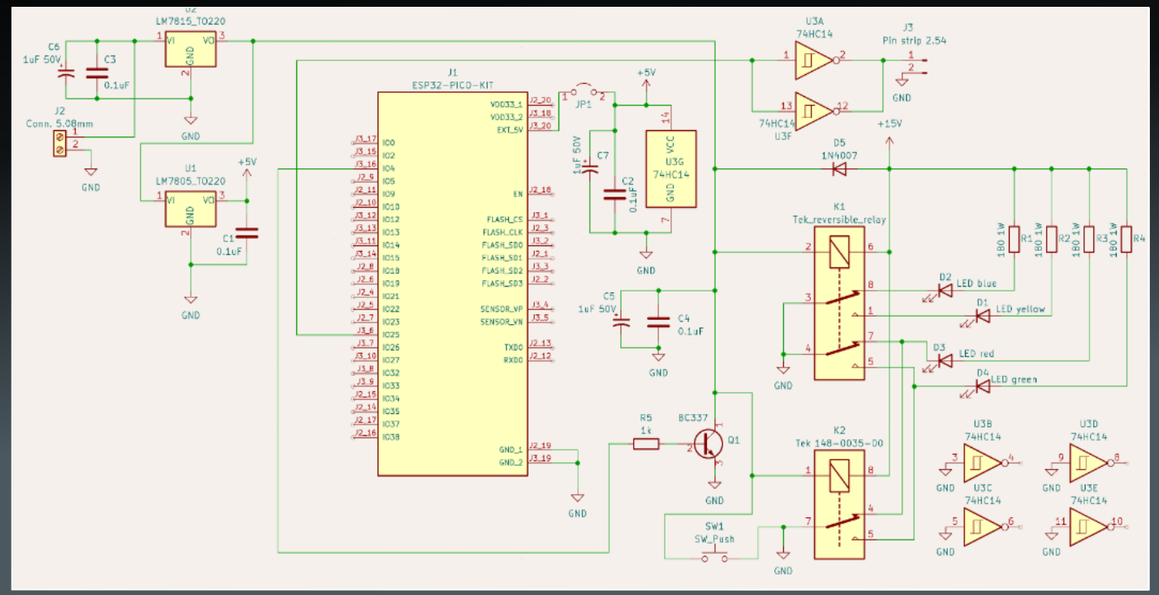
A Relay Exerciser

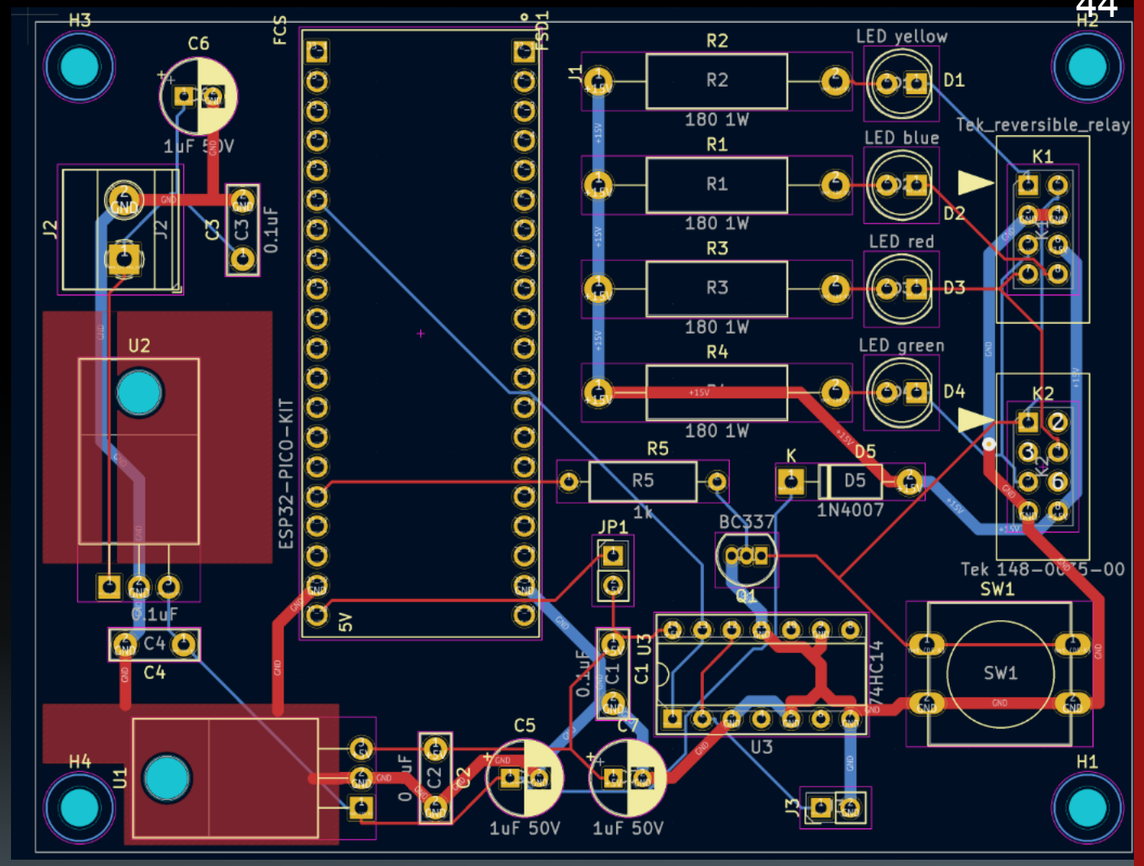
This gadget can help you to rejuvenate the terrible Tektronix relays. It is based on a Epressif32-Pico-kit microcontroller, that does really little… It just produces the signal to drive repeatedly the relay. Pressing its BOOT button, you can cycle the command period among 1000, 500, 200, 100, 67 ms. It requires 24V a power supply at J2 and can host, in two different sockets:

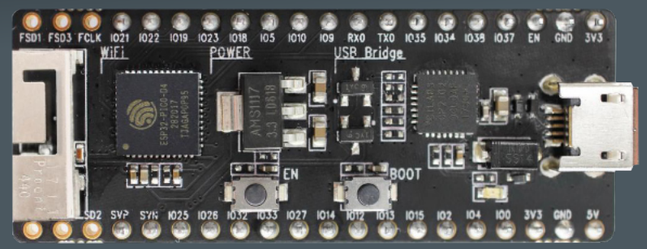
- the typical reversible Tektronix relays like 155-0034-00, 155-0034-00 etc. (see their genial pinout here on the right);
- those like the 155-0035-00.

You can see the schematic here below, and the layout on the page at right. On my web site you can download the Gerber files, the Kicad sources and the Arduino project for the software.









Above. KiCad is a free software suite for electronic design automation (EDA). I started to use it to build this simple circuit, and I loved it immediately. After 15 years since my last board design, in just one day I could feel comfortable enough with it (don't blame me if it is not perfect, I am no longer an hardware designer…).

Left. ESP32 is a series of low-cost, low-power system on a chip microcontrollers with a lot of integrated peripherals. They can be programmed using the Arduino tools, generally in C++ or Python, and are very easy to learn, also for the huge availability of information, support and reference designs, ready to be used.

WD40C enema

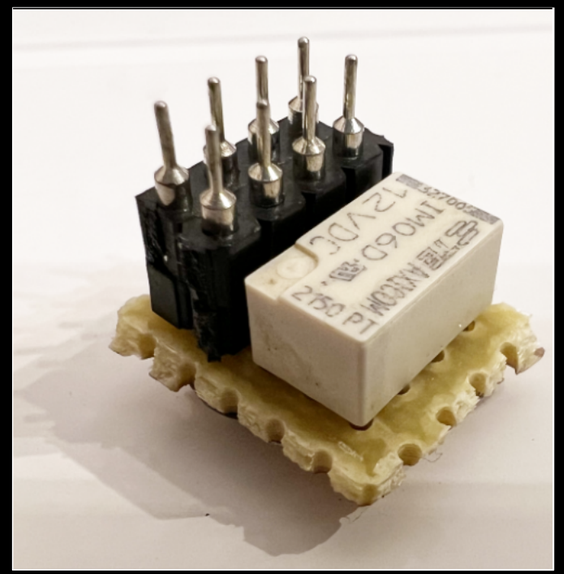
After having collected some more experiences on this topic, I add (E05) some notes that can help you when you need to fight against these little monsters.

The first point I wish to emphasize is that the exerciser cure sometimes is not for ever. The rejuvenated relay may work well for some weeks (or less) and then stops working. For this reason I suggest to add a restorative: a WD40 Contact treatment. To apply it, carefully create with the Dremel two little holes on the relay edges, as shown in the photo. Avoid inserting the tool inside, or you will destroy the relay. Why TWO holes? Because one is used to spray the WD40C inside the relay, and the other lets the air to get out. With still some WD40C drops inside, put the relay in the exerciser and let it run for some hours. Eventually, after the complete dry of WD40C, you can seal the relay with some glue.

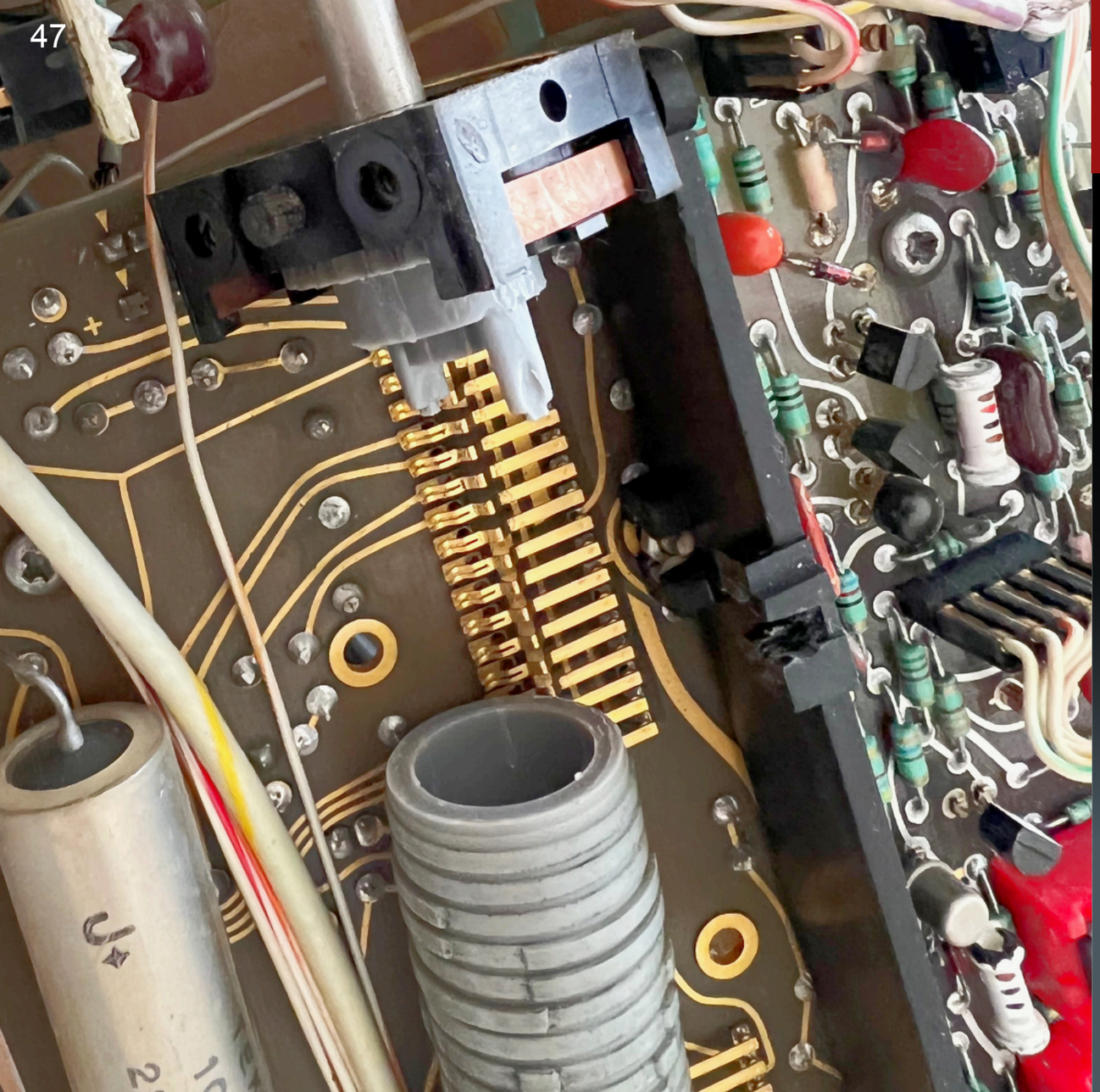
Build a new one

When everything else failed, the last hope is building a replacement. To fix one of my two 7A13s, I used a 12V DPDT Axicom IM06D (Mouser code 655-3-1462039-8), as you can see in the photo below.









Switches & Buttons

Cam rotary switches and push buttons problems due to false contacts of are perhaps the most common (and they were also so, when the equipment was new and young).

In most cases, the problems are due to dirt. Fixing them is not always simple, especially when the contacts are not easily accessible. You can try to flood them blindly with Isopropyl and then dry with low pressure compressed air, but, according to my experience, that is not the best approach; you should look and check the contacts to clean them correctly. Note that sometimes accessing the contacts is easier than you can imagine. For example, initially I did not understand that the attenuator blocks in 7A18, 7A26 etc. could be easily removed, just pulling them.

When possible, the best is a complete wash using a strong de-greaser (I use Chanteclair) and plenty of clean water (better if distilled), but this approach requires drying the board in an oven or at the summer Italian sun. However, I had good results also using a product like WD40 Contacts (not the standard WD40!), helping the dirt removal with a small, very soft brush.

In the most difficult cases, it can be a good idea to well analyze the problem and identify the precise contact causing the malfunction, before trying a generalized washing. In other words, use your brain to identify the wrong contact and operate on that. In the case of 7A18/7A26 attenuators, you can set the knob to 5mV/div (i.e., no attenuation) and place the VOM, in “beep mode”, between the in and the out of the attenuator. The VOM should beep. Then move imperceptibly the knob. If the beep ceases, try to find the critical switch with a toothpick.

Normally, push buttons as well can be cleaned with plenty of WD40C (again, not WD40!) , operating them repeatedly.

For other tips, see also the Tektronix “Cam switch repair manual”, that you can find rather easily online.

In the photo: a less common problem (I suppose): the hub of the cam cylinder in a 7B53 has come unglued. I doubted I could save it, and fixing was not easy. The problem was to glue the cylinder in the exact position respect to the hub. By comparing with a good 7B53, I could succeed, but two attempts have been necessary.

Dealing with Gold

Dr. Hugo Holden, hugo.holden9@gmail.com

As I told you, I do not consider myself an expert but just a passionate lover of Tektronix oscilloscopes. I am proud to have received a significant contribution from a true expert. I asked him the allowance to report his really valuable experience, and here is...

I read your book and I have something to add in how to deal with the problems of the touching Gold contacts in the Tek 465's attenuators (and other similar Tek scope equipment). I have specialized in fixing these over many years.

A problem crops up over time with touching contacts, where at least one or both are Gold plated.

Although we are taught to believe Gold is non-reactive and doesn't oxidize, over time it acquires a very thin film, an optically transparent surface insulating film. There is no problem with it in switches where the contacts slide on each other. The problem crops up where the contacts are touching. And also where the voltages applied across the contacts are very low and cannot break down the film. Therefore the types of affected components include:

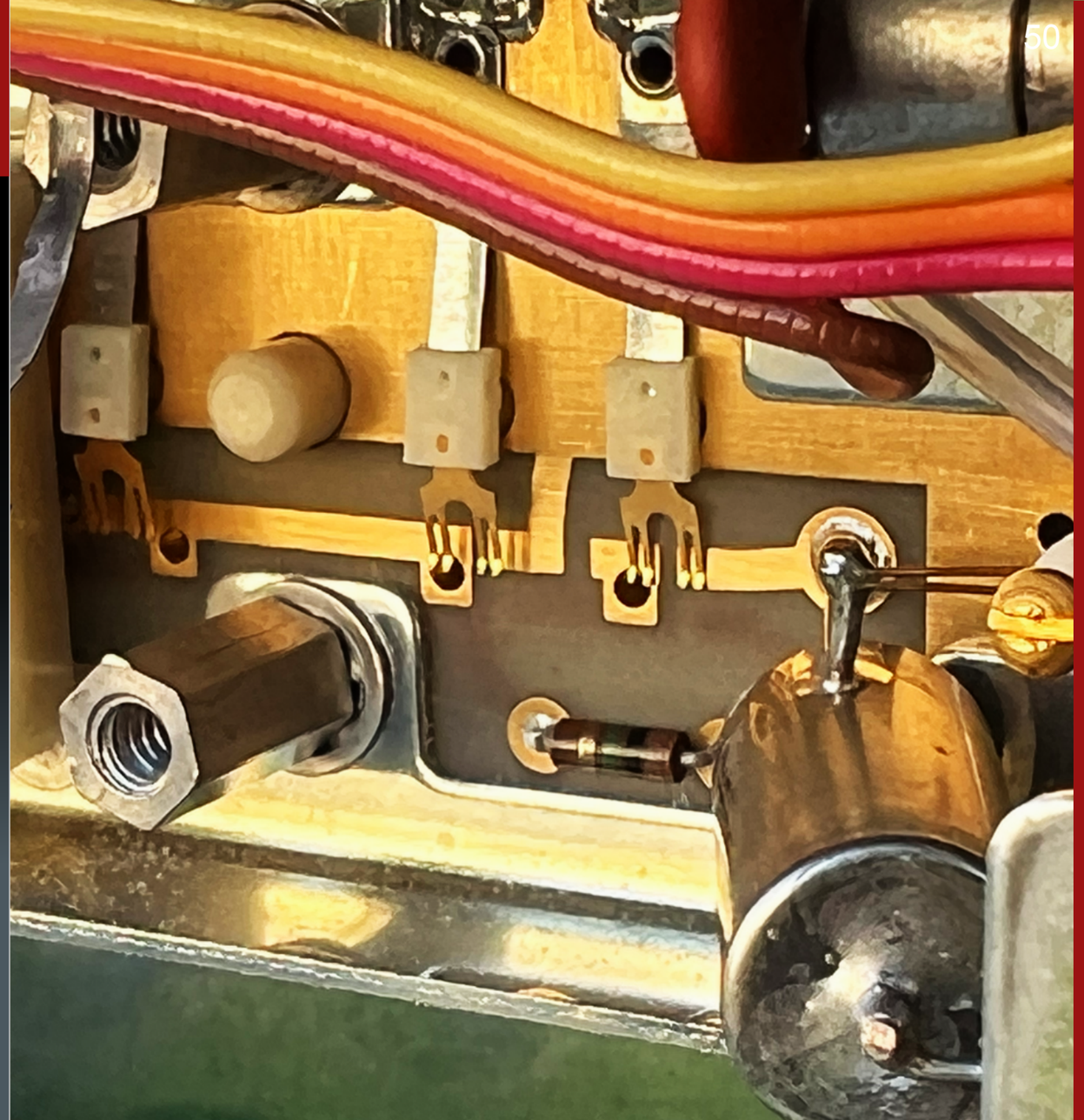
- *Tek attenuators and some of their other switch assemblies.*
- *DIP switches with touching contacts.*
- *ZIF IC sockets (typically on some CPU's in vintage computers)*
- *The target electrode connections , typically on vintage single tube color cameras.*

In the last case the effect of resistance developing in this connection results in the loss of the 7MHz color carrier that encodes Red & Blue, so the camera image goes Green.

DIP switch failure on vintage computer PCB's cause chaos. Most of the early DIP switches from 1970's computers should be replaced as they cannot be cleaned.

The only way to effectively clean aged Gold contacts is with a combination of some friction and CO contact cleaner. But the friction cannot be too much or it damages the Gold surface.

The suggestion of using fine abrasive paper should never be made. Even 2000 to 4000 grade paper, regarded as fine paper in the field of paint finishes, should never be used on the contacts in Tek scope attenuators. And any form of spray cleaner on its own won't work as the glassy surface insulating film still remains.



The way to clean these contacts is to cut up some A4 printing paper (this is about as coarse an abrasive surface that should be used). The strips are cut to be about 4 or 5mm wide and about 15mm long and a sharp fold is placed in the strip to make a right angle bend.

The paper is initially held with forceps and with the switch arm open one end of the paper is slipped under the contact, and then the switch manipulated until the contact closed and the paper then is trapped between the switch surfaces. Then the paper is sprayed with contact cleaner. After this the paper is withdrawn, making sure to keep it parallel with the PCB surface, never pull upwards on it, or, it will bend the spring contact arm up weakening the spring tension.

When the paper is withdrawn it is still wet with the contact cleaner. The switch is opened again, the paper placed under it, the switch closed again and the paper withdrawn again. This process is repeated as the contact cleaner dries out of the paper. Some contacts require about 5 to 7 withdraws of the paper before the surface is properly cleaned.

In the Tek 464/466 scope, there are as many contacts on the top of the PCB in the region of the attenuator modules, as there are below on the other side of the PCB. In these scopes the entire assembly must be removed to be able to get at properly clean those on the bottom surface.

A cleaner with any form of residue should not be used, which is why CRC's CO contact cleaner is suitable.

(One way to fix up the ZIF Gold plated socket and pin connections in vintage computers, especially the ones with the Gold plated pin Athlon 64 CPU's, is to create spacers about 1.5 mm thick around the cpu, so it cannot fully be pushed into the socket, then partially close the ZIF socket arm to give just enough tension on the socket & IC pins, then remove the spacers and push the IC home. The sliding friction breaks down the surface film, which never happens with normal use of the ZIF socket).

The oldest Tek scopes I have are the 464 and the newest the 2465B. I written a number of articles on Tek scope repairs & modifications for the 2465B. Though here is an article that might interest you about the 464/466's because the principles of Vertical amplifier frequency response apply also to the older generation of Tek scopes.

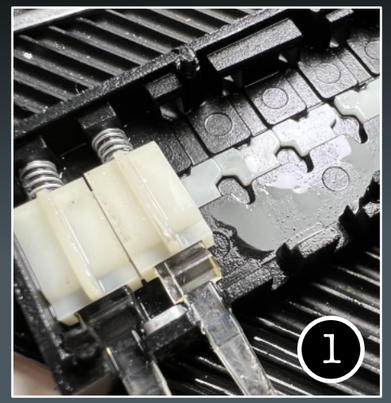
One thing that impresses me about Tek designs, is that they were incredibly creative, novel, ingenious. Once I reverse engineered a military grade Conrac VDU and discovered an amazing and creative circuit in it. After a lot of research I discovered that this unique black level stabilization circuit, was invented by non other than Tektronix in the late 1960's. Have a look at the end of this other article and the brilliant circuit they came up with.

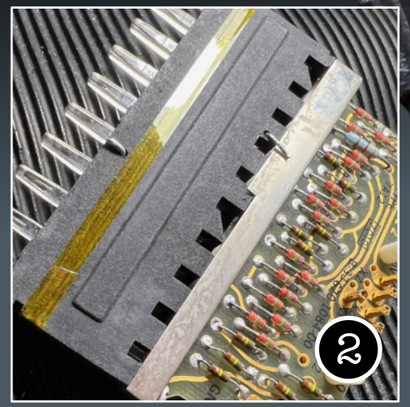
Light Pushbuttons

If I am not wrong, the first pushbutton type was that here reproduced, that I call “pin type”, constituted by a small transparent plastic stick. They had a nice feature: when you press them, the tip gets illuminated (see next page to see the effect), and that is done with just one lamp for a row of buttons. After a lot of years, these buttons may become critical, especially for the dirt which enters the gear, so they need to be dismounted and cleaned. First suggestion: don’t open them unless absolutely needed. This not for their complexity, that requires much of attention and patience, but because they are not designed to be serviced. So, once you have repaired them, there is not a defined way to close them again; the cover is kept in place by small plastic point that cannot be restored when broken. I made some micro-holes and used the rheophore cut off a resistor as closing pin.

❶ The small white shapes have the purpose to make impossible to press two buttons together. They are responsible of the keys hardening. After having well cleaned them and their seat, apply a micro amount of proper grease or vaseline.

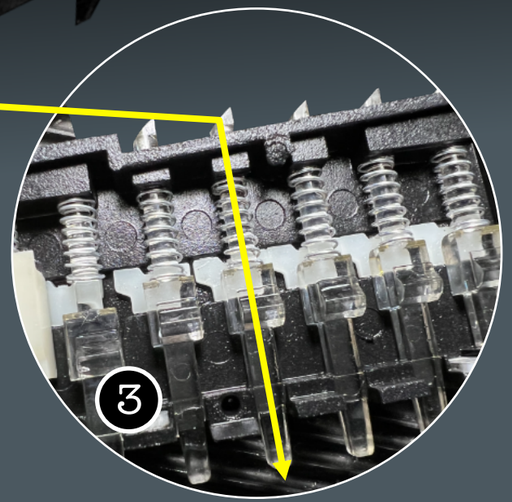
❷ The reworked pushbuttons assembly. Note the new closing pins and the tape to help closing.





❹ This bar is responsible of keeping the button depressed and to release it when another key is pressed. Be sure that can freely move and that its spring is correctly placed.

❸ How does the light magics work. Normally, only one key is depressed and its tail protrudes on the back side of the buttons case. This tail is 45° cut, so it reflects part of the light toward the button tip. Today everybody would use a LED for each button, a microcontroller, a lot of software etc. At that time you had to manage what you had...



A Christmas Tree

As we told before, the typical Tektronix transparent pushbuttons are enlightened with a very ingenious system that uses just one or two bulbs per row. Thanks to their geometry, only the pressed one conduces the light to its tip. The resulting “Christmas tree” effect is very nice and the enlightened tips makes it easier to understand which button is depressed.

Note that not all the plug-ins are enlightened, even if they have these pushbuttons. The most glaring case is the 7B53A, so don’t worry if only the single sweep button has the light, it is not a fault but a designer’s decision.

Neither do the three-bays mainframes like 7603 and similar, which have not the necessary power supply for the lights; but they can be easily modified as explained on next page.



The genial gear, described in the previous pages, that ensure the illumination of the Tektronix pushbuttons. They are not powered on the 76xx oscilloscopes. The plastic part subject of the photo belongs to a 7B70 plug-in, that had all the bulbs burned out. I has obvious signs of molding. Perhaps it received an over-voltage, that caused overheating and filament destruction.

Lamps

At first I believed that replacing a lamp could be very easy, but nothing is free, and Tektronix did not make things easy. There are many kind of lamps, and they are not everywhere available (i.e. in Europe); on eBay they are furthermore often unreasonably expensive.

A good place to buy them is Bulbs.com, 234 Stafford Street, Worcester. MA 01603 (customerservice@bulbs.com), but, if you too live in Europe, you will have to pay the shipment, wait and wait, and pay the custom.

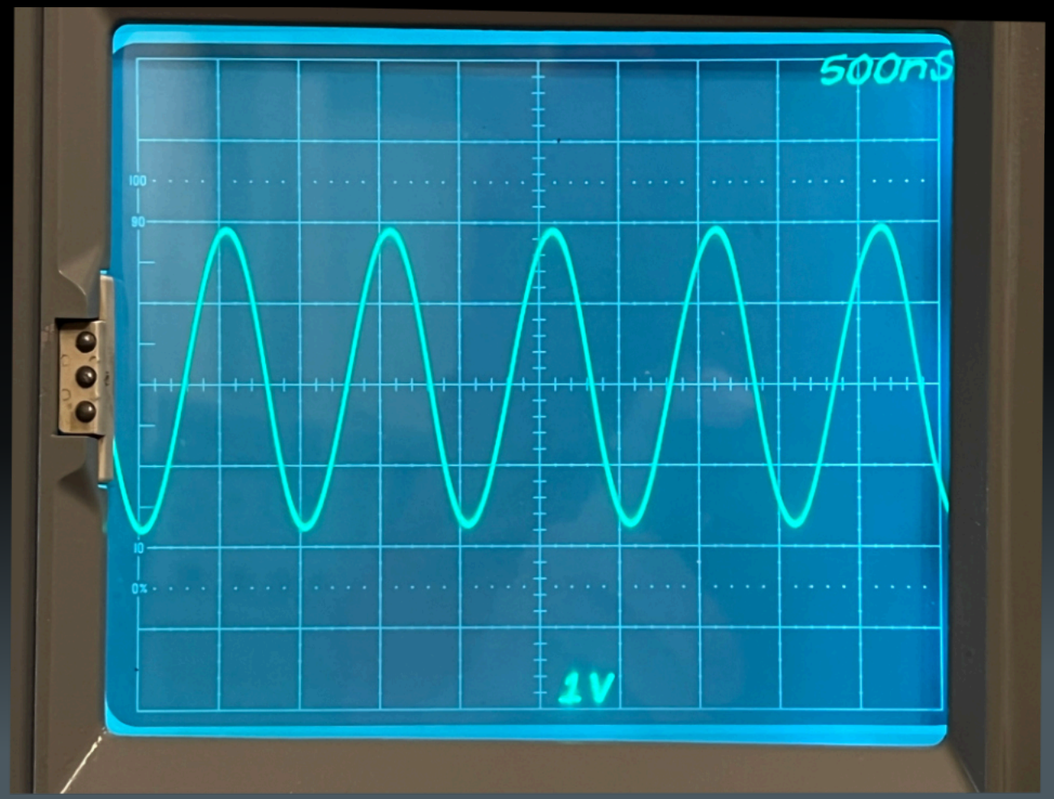
There are millions of lamp types, in millions of variants. Most of them are identified by an ancient code, but often not unique.

Until now, I came across three lamp types:

- 150-0047-00, aka “#398”, 6.3V, 0.2A, dia 5.9mm - it is used for the graticule illumination of the 7603 and other with the same size CRT (es. OS-245(P)/(U). They are removed pulling from the front (be careful, they break easily);
- 150-0029-00, aka “#349”, aka “7381”, 6.3V, 0.2A, dia 6.2mm - it is used for the graticule illumination of the 7904 and other with the same size CRT (es. 7844, 7623, 7633…). They are removed from the rear, moving slightly a clip. I bought them from Bulb.com;
- 150-0048-00, aka “#683”, 5V, 0.06A, dia 3mm - it is used for the pushbutton array illumination (that described here some pages before). They are soldered and not easy to change. In many cases, it is necessary to disassemble a lot. I replaced them with the Mouser 606-2 (5V, 0.02A, dia 2.2mm, that are bright enough).



LED Lights

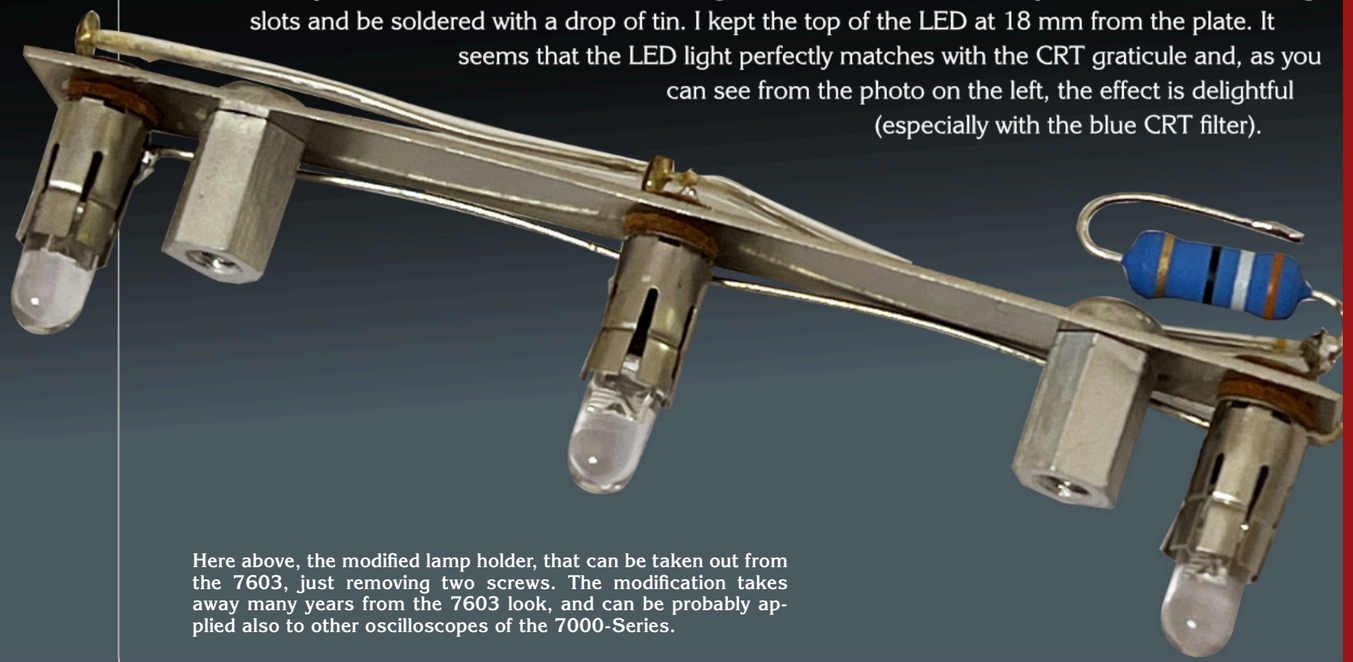


Here I suggest you a little facelifting for our old friends: replacing the graticule illumination lamps with modern LEDs. I am normally a maniac of absolute originality, but the effect of this modification is so nice that I made an exception.

The idea is not from me but from a Youtube video by Zenwizard Studios. I just add some bits of information. In this case, I applied it to a 7603.

I used high-efficiency 5 mm white LEDs that I bought on Internet. Today LEDs are absolutely fantastic. These are rated for 50 mA, but they seem to go much further, even if probably with a shorter life. In theory, you should add a resistor for each of them. The author of the idea used no resistors at all, but I found prudent to add at least a 39 Ohm, ½ W resistor in series to them all, also because it is useless to use too much light.

Mechanically, I used a drill with 1 mm tip to remove the internal original spring and used the existing hole for the positive terminal of the LED (the longer one). The other lead can pass between the existing slots and be soldered with a drop of tin. I kept the top of the LED at 18 mm from the plate. It seems that the LED light perfectly matches with the CRT graticule and, as you can see from the photo on the left, the effect is delightful (especially with the blue CRT filter).



Here above, the modified lamp holder, that can be taken out from the 7603, just removing two screws. The modification takes away many years from the 7603 look, and can be probably applied also to other oscilloscopes of the 7000-Series.



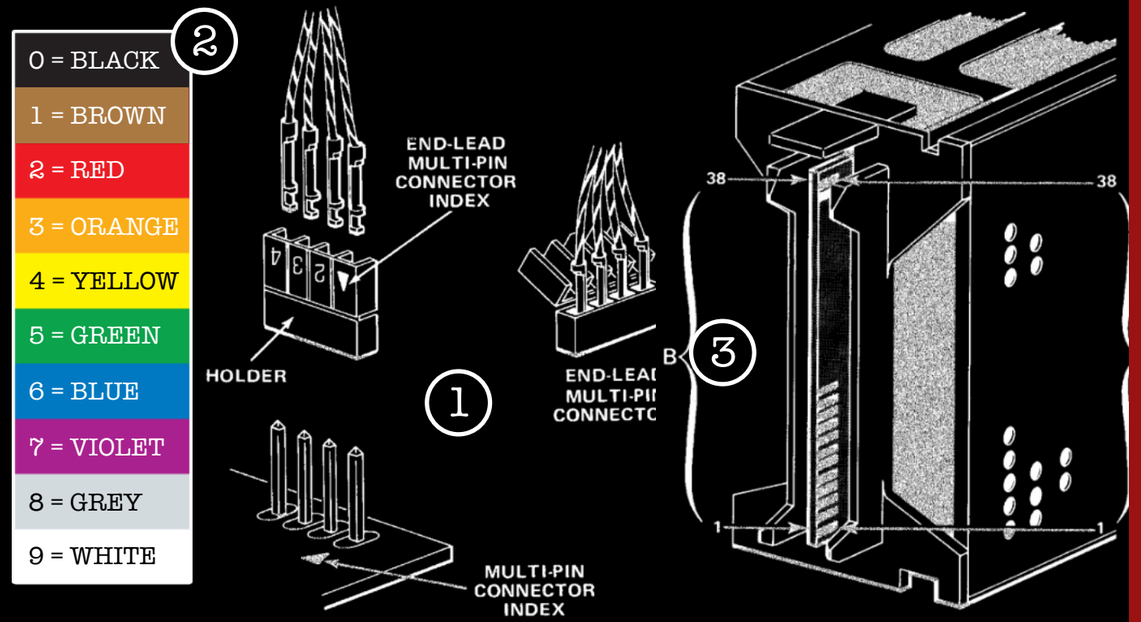
Risky Connectors

I will never repeat enough that one of the bigger risks working on 7000-Series is making mistakes inserting the flat cable connectors in the wrong way: shifted one place or reversed. Always check them three times before switching the power on. I noted the ❶ drawing for the first time in the 7A16P manual; I believe it can be useful also for you, and so I report it here below.

Remember always that the wire colors can help you avoiding mistakes; they follow the same resistors' color code as the resistors (❷). Even when they seems to be white, normally they are striped. So the pin 1 is always the brown.

Note that all the cables in 7000-Series are 24 AWG 100 mils pitched (2.54 mm), not 28 AWG 50 mils like the most common crimpable type. As connectors, common AMP Modu 2 can be used. Suitable

In ❸, the plug-in connectors numbering.



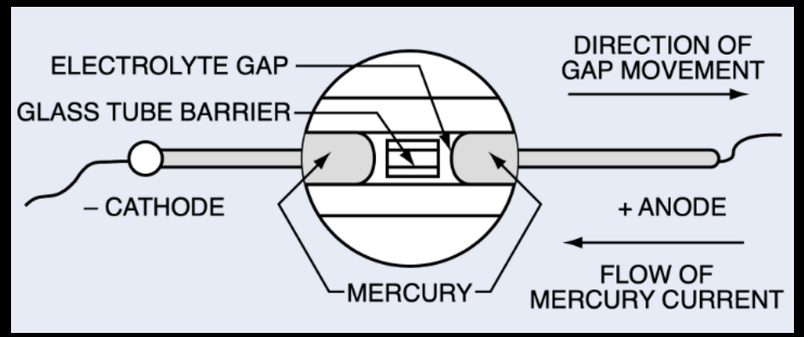
Elapsed Time

I am going to describe something that, in my long professional life, never heard before: the chemical work-hours counter. Their correct name is “analog Elapsed Time Indicators” (ETIs) and they use an electro-chemical plating process to integrate current over time. They are produced by Curtis. In the large photo, the 7704 Low Voltage board with a Curtis Indachron on board.

Curtis ETI are used to measure use time/counts for preventive maintenance scheduling, warranty witness and MTBF measurement on medical and scientific lamps, power supplies and telecommunication equipment. These devices can also be used to integrate current for solar cells and portable, battery- powered equipment. Curtis hour meters were used by NASA in the Apollo project to monitor all major electronic systems. More than 40 Curtis hour meters were installed in the space vehicles and over 20 are still on the moon today, left behind on the moon with the descent module.

How do they work

The integral is achieved by passing current through a precision-bore glass capillary tube. The glass tube is filled with two columns of mercury, which are separated by an electrolyte gap.



Application of current causes the mercury at the anode to be electrochemically transferred across the gap to the cathode at a rate which is proportional to the current. Thus the gap moves along the capillary tube and provides a visual indication of the current/time integral.



During the tests, I checked also some of my surplus equipment. I had heard something on old milliammeters and so I I wanted to verify if the rumors were true.

Surprise: one of them was somewhat active, as you can see by the photo. It was cathode and grid measurement of the T-195 transmitter, part of the GRC-19 station, a real technology jewel, the absolute top for the fifties. You can find a complete description of it in my other book "Surplus parade", downloadable from the same web page as this document.

Note that there are other two similar instruments, but they are not original, perhaps they had been substituted previously, exactly for this reason.

The radioactivity comes from the fluorescent painting that should have made them more readable in the darkness.

I put this instrument in the cellar.



Radioactivity

One of my friends claimed that an old oscilloscope, with its high acceleration potentials, had to emit some kind of radioactivity. That topic came out also when CRTs were used in television or in computer monitors. For example, you can find this study on the Internet:

> While surveying used computer equipment out of a zone posted as a Contamination Area, 100% of the computer monitors surveyed had levels of radioactivity that were significantly above background. The radioactivity was primarily on the front face of the cathode ray tube and was not amenable to decontamination. Hot spots were found also along the edges and seals of the cathode ray tube. Similar surveys of computer monitors that were never in Contamination Areas confirmed that radioactivity was incorporated into the monitor. Surveys were made of recently manufactured television sets with similar results. Gamma spectroscopy indicates that the radioactivity is due to naturally occurring radioactive materials. Since most surveys of cathode ray tubes in the literature were made while the units were energized and indicated low-energy x-rays, the use of naturally occurring radioactive materials in the manufacture of cathode ray tubes has not been widely recognized. This paper presents the results of these surveys, the results of gamma spectroscopy, and a method for releasing existing computer equipment having naturally occurring radioactive materials (https://pubmed.ncbi.nlm.nih.gov/14744065/).

I am in general rather wary on these themes; you can find studies for almost anything, demonstrating its terrible dangers. I am sure, that someone demonstrated that even pillows present terrific hazards.

But I was curious, and so ordered a very nice and inexpensive "Nuclear radiation detector" from China, and made some tests.

I do not affirm the scientific validity of these tests, but for what I could see, the levels on the CRT front are almost the same as those of free air (6-20 µSv/h at home).

A surprise from an old military equipment of mine, as shown on the page on the left.



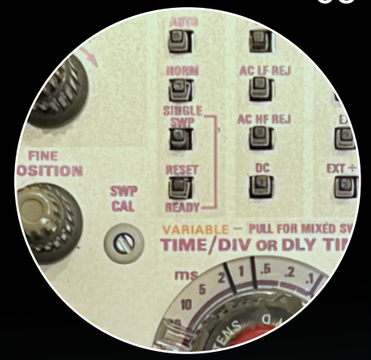


Plug-in Panels

The plug-in panels are generally rather easy to dismount, once you have removed all the knobs (they are simply “snapped” on the body). They are incredibly resistant, and I could even clean them with nitro-diluent without any vanishing of the writings, and, if they are not scratched, can return as new. But few days ago I noted a things that I could not explain. One of my 7B53A had better colors than the others (see the green in the photo below). Why? A change in the production? It seemed rather strange, because I own another 7B53A with almost the same serial number.



Eventually, I think I explained it. The “different” 7B53 is coming from my 7623A, that, according to my reconstruction, spent some decades under a protective cover. So, I checked also the 7A18, coming from the same oscilloscope, and I got the confirmation: also the 7A18 has a far better green in the TRIGGER SOURCE zone (see below). Conclusion: the light contributes to aging….



Here on the top in the circle, another mystery: the vanished writings of a 7B53A. All the panel has the same uniform effect, so it was not a liquid or something like that. Even beneath the transparent crown of the knob, writings are discolored. I was not able to find an explanation.

Tubes Test

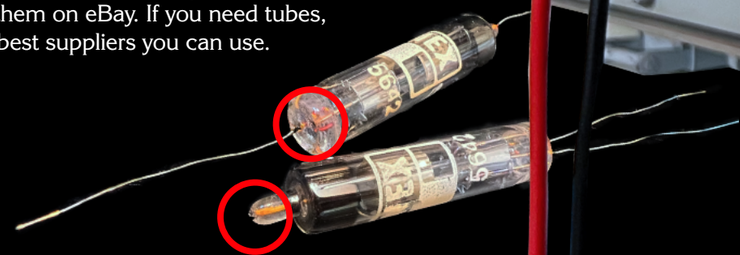
If you want to work on these old traps, definitely you need a tube tester; the best one is probably the glorious TV-7A, which I received from my dear friend Francesco Sartorello, whom I never stop thanking. It allows to check most of the tubes that you need and you can find it in my book “Surplus photo-parade”, as described on page 12.

Testing the 5642 HV diodes

Having to repair the HV module, I started from checking its five 5642 tubes, high-voltage rectifiers. This tube also is included among those that the TV-7A can manage. But I had to understand how to connect it for the test; the manual says nothing on this point. The tube has only three terminal, two for the filament/cathode, and one for the anode. You can use the setup shown in the big photo here: the thick red and black wires go to the filament and the thin black goers to the anode. You must press key 7 for the test and the minimum reading is 4. In this way I discovered that all my tubes but one were exhausted. No problem, I thought, I have some spare. But when I opened the box, I discovered that the “new” tubes were defective (broken pins, see below).

A nice story

I purchased them five months ago on eBay. I believe that probably they were good when shipped, but the thin old wires were so corroded by years that unexpectedly broken. So I wrote to the seller, who could easily tell me “what do you want by me after five months?”. On the contrary, they were very kind and offered me a refund or other tubes (which was I wanted). So I can't help but thank them and tell you their name: they are **electricslee**, with 257,000 sold objects and 2,600 followers; you can easily find them on eBay. If you need tubes, they are sure one of the best suppliers you can use.



Gassy Tubes

What's the problem?

High on the list of phenomena which contribute to tube failures, and which are of an evolutionary nature, is gas. The first tubes have been produced just pumping the air out of them, but the most common solutions was using **getters**. A getter is a deposit of reactive material that is placed inside a vacuum system to complete and maintain the vacuum [Wikipedia], and is the silver area on the top, visible thorough the glass.

Always to be replaced?

The presence of gas in a tube does **not necessarily mean** it has reached the end of its useful life, or its life expectancy will be less than some other tube. Tubes have been manufactured without getters. Using conventional "grid testers," these tubes were very "gassy." Yet, when placed in controlled life tests and compared with similar tubes that had getters but showed little or no gas indication, these so-called "gassy" tubes outlived and outperformed their more normal mates. Why should this be so? The answer is not well understood, even by tube engineers [Robert B.Tomer, *Getting the most out of Vacuum tubes*, Indianapolis, Bobbs-Merril, 1960].

Checking tubes for gas

Howsoever, when possible, it is advisable to check this parameter as well. The magical TV-7A allows this test. To do it you must:

- press the button GAS 1 and adjust the BIAS knob until the instrument shows "10";
- keeping GAS 1 pressed, press GAS 2 as well. The pointer should not move more than one scale small division.

I found that many tubes, not only in the 545 but also in the newer 545B (e.g., the 6DJ8), result to be somewhat gassy, but they seem to work well, so I see no reason to replace them.

Often, a strongly gassy tube can be acknowledged also by watching it: when the getter's top silver disappears, it is a sign of this phenomenon. Here in the photo, a 12BY7 from my 545. In the beginning, it could almost pass the TV-7A mutual conductance test, but, inserted in the circuit, it didn't operate. Checked again, the test failed and I had to buy a new one.



Other Tools



ZM-11B



ZM-3/U

Here in these pages two instruments very useful to operate on old devices: bridges to check old components, such capacitors, inductors and resistors. The latter can be better tested with a modern VOM, but for capacitors I found nothing better until now. You can find their description in my book “Surplus photo-parade”, together with the tube tester TV-7A, as described on page 12.

Ceramic Strips

Another relevant preliminary information is related to the basic construction technique used in old Tektronix tube-oscilloscope: the ceramic strips, where most of the passive components (mainly resistors and capacitors) are mounted. They are very practical, because thanks to them, you can access, check and, if required, replace most of them with a little effort.

Keep them clean

The ceramic strips turned out to be quite reliable. If they aren't abused, the only known failure mode is when they are used in HV supplies and are allowed to get very dirty. The dirt can become conductive, resulting in unintended current flow over the surface of the ceramic strip, silver migration, and/or arcing. Once arcing occurs, heat from the arc would fire the silver into the ceramic, causing a permanent short that cannot be reliably cleared – such a strip must be replaced. This can be avoided by keeping the HV circuit clean. I use specific products, like PCC shown here below.

Soldering instructions

Tektronix warned that their ceramic strips should only be soldered with silver-bearing solder (3% Ag was recommended). I extracted all the above from TekWiki (thanks!). I wish I had known it earlier, because I raged with the soldering iron without any precautions.

Soldering precautions (from the manual) - In the production of Tektronix instruments, a special silver-bearing solder is used to establish a bond to the ceramic terminal strips. This bond may be broken by repeated use of ordinary tin-lead solder, or by the application of too much heat. However, occasional use of ordinary solder will not break the bond if too much heat is not applied.

It is advisable that you have a stock of solder containing about 3% silver if you frequently perform work on Tektronix instruments. This type of solder is used quite often in printed circuitry and should be readily available. It may also be purchased directly from Tektronix in one-pound rolls (order by part number 251-514).

Because of the shape of the terminals on the ceramic terminal strips you may wish to use a wedge-shaped tip on your soldering iron. A tip such as this allows you to apply heat directly to the solder in the terminals thereby reducing the heat required to melt the solder. Since excessive heat can destroy the bond of the terminal to the ceramic material, it is important to use as little heat as possible. Also, the wedge-shaped tip is desirable from a convenience standpoint, since it is easier to work on the ceramic strips with this type of tip. Early instruments often contained a small spool of suitable solder inside the cabinet. Today, some suitable solder types containing silver, e.g. Sn62Pb36Ag2 (2% silver content, 179°C melting point), are still available.

The PCC can and the original spool of solder in the RM561B scope, pointed out by the red arrow. It is still there, after so many years.



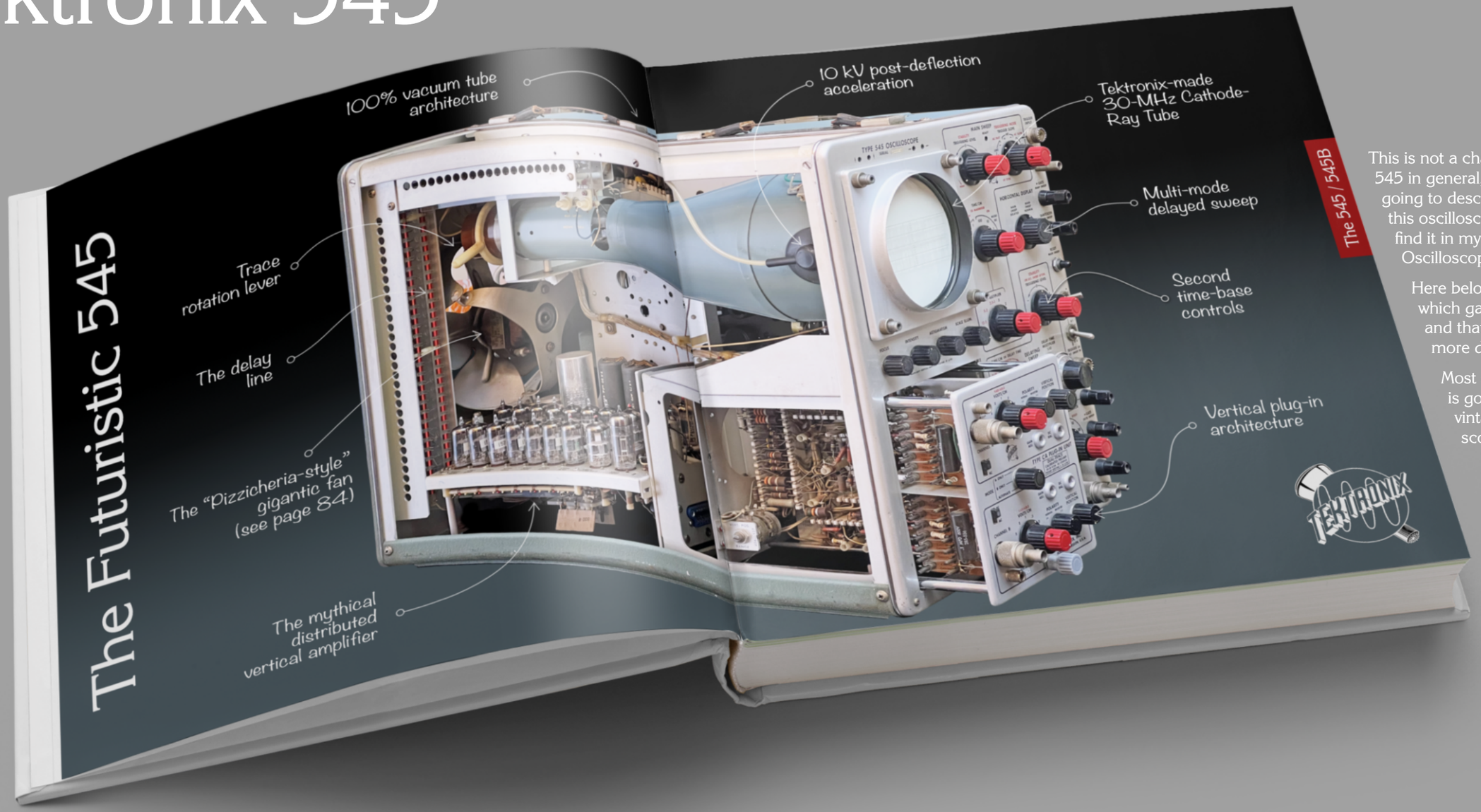


500 Series

Fixing the epic 545

In this chapter, the story of some repairs on my 545 and 545B. When arrived, the former was completely non-operative, with missing parts, and required a sensible effort. The second, the 545B, was in a much better condition. Working on these old machines is less difficult, because components are easier to access and the circuits simpler than the following transistorized units. In addition, I hope I made things simpler reporting the component map of almost the whole 545, not present in Tek manuals.

Tektronix 545



This is not a chapter about the 545 in general, so I am not going to describe in detail this oscilloscope. You can find it in my "Tektronix Epic Oscilloscopes" book.

Here below just the parts which gave me troubles, and that I had to study more deeply.

Most of what follows is good for many vintage tube scopes.

Poor Teddy Bear!

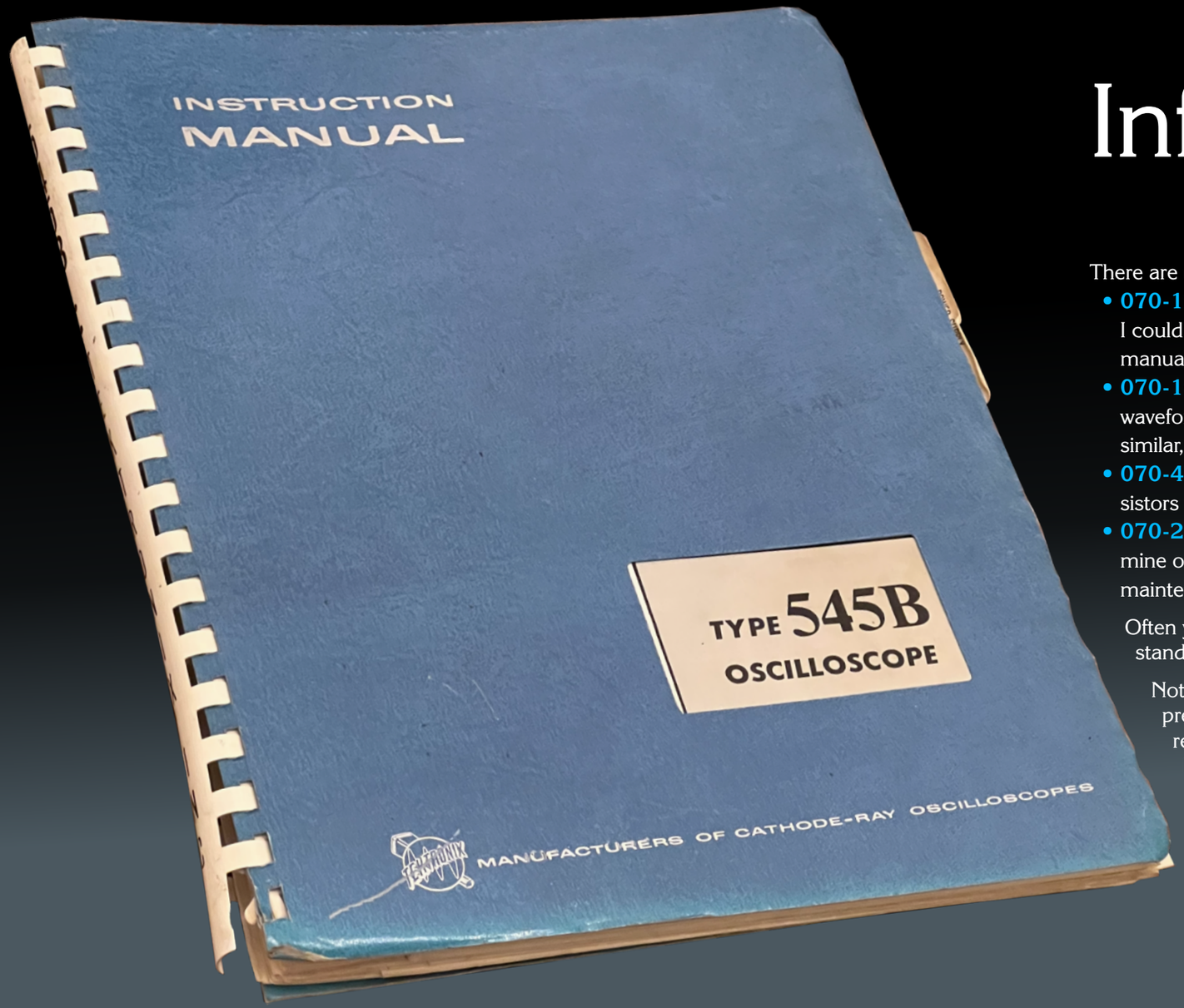
For writing the *"Tektronix - Epic Oscilloscopes"* book, I bought two 545s. The first, **a true 545** (i.e., not a 545A neither a 545B), arrived here really beat up and not complete from Sicily, one of the most southern Italian regions, where probably it had been used for many years before it got faulty and someone tried to repair it, with non-exceptional results, as you can see in these pages. The fan crashed down, a tube was missing, others where faulty, and the High Voltage section was partly dismounted. As usual, I could not resist the temptation to switch it on, but a bad smell stopped immediately all my ingenuous hopes. The restoration should be afforded in a more ordered way, and you can find here almost its whole story.

The second is a **545B**, i.e., the latest expression of this model. In it, the display area had been increased from 4 x 10 cm to 6 x 10, and its circuit had been modified to replace some tubes with transistors. I find extremely attractive this hideous technology mix!

If at the beginning it seemed impossible to resurrect the 545, the 545B was in very good conditions. A small repair was needed, and this is described in the following as well. In addition, the 545B arrived with its original manual, something that I greatly appreciate.

As you can image, following the **Broken Teddy Bear's Law**, the apparently incurable 545 immediately became my favorite, and when I saw again life signals in its CRT, the joy was immense…





Information sources

There are more documents for helping you fixing a 545:

- **070-198**: the original 545 manual. In the pdf normally available on line, a page is missing (3.10). I could get this page from the friends of Tekscopes GroupIO. An OCR integrated version of this manual is available on my web page;
- **070-163**: the 545A manual. It is much better than the above one; it includes many voltages and waveforms in the circuit. Some schematic part is differently drawn, but many circuits are rather similar, if not identical, to the 545, so a "controlled" use is often possible and convenient;
- **070-428**: the 545B, sometimes similar, sometimes completely different (somewhere, it uses transistors instead on the original 545 tubes);
- **070-282**: *"Tektronix Type 545 Oscilloscope Calibration & Maintenance Procedure"*. A real gold mine of information, not only for the calibration but also for the repair, clearly written by expert maintenance personnel. I learnt that reading it before any intervention can save effort and time.

Often you have to "average" the available information, studying all three. The best is first understand the circuit and then work. Much information is in addition available on Internet.

Not always the original description is as clear as you wanted. The intention of this document is precisely to come to your aid. In addition, you can find here the component layout with the reference designators ("refdefs") for most parts of your oscilloscope, a tedious work that I hope can be useful to all those who are going to afford these monsters' restoration (including 535 and derived).

Original manuals can be easily found on eBay. An original manual is a pleasure for the collector, and their quality is much better than the pdf you can download from Internet.



500 Series

Subsection: LV Power Supply

For Low Voltage we mean all the voltages up to 500 V, i.e., not the High Voltages for the CRT. Don't be fooled by their name: they are more dangerous than the HV.

Differential Amplifiers

To better understand what follows, it is advisable to remind something about **differential amplifiers**, because this circuit is used very often inside most Tektronix products.

A **differential amplifier** (DA), in a short, is an amplifier that amplifies the voltage difference between its inputs. More precisely, according Wikipedia, a differential amplifier is a type of electronic amplifier that amplifies the difference between two input voltages, but suppresses any voltage common to the two inputs. It is an analog circuit with two inputs Vin+ and Vin- and one output Vout, in which the output is ideally proportional to the difference between the two voltages. A DA can be implemented with ICs, transistor or tubes.

The basic DA circuit is very simple, and its operation intuitive. If you apply the same voltage to both inputs, you have the same voltage at both outputs. With reference to the picture, If Vin+ only is increased, the left tube conducts more, and its current grows, but on the cathodes there is just one resistor. So the extra current of the left tube determines a reduction in the right tube. In consequence, the change of the outputs is proportional to the voltage difference between Vin+ and Vin-.

Let's add some more precise information from Wikipedia:

Biasing: In contrast with classic amplifying stages that are biased from the side of the base (and so they are highly β-dependent), the differential pair is directly biased from the side of the emitters by sinking/injecting the total quiescent current. The series negative feedback (the emitter degeneration) makes the transistors act as voltage stabilizers; it forces them to adjust their VBE voltages (base currents) to pass the quiescent current through their collector-emitter junctions. So, due to the negative feedback, the quiescent current depends only slightly on the transistor's β.

Common mode: in common mode (the two input voltages change in the same directions), the two voltage (emitter) followers cooperate with each other working together on the common high-resistive emitter load (the "long tail"). They all together increase or decrease the voltage of the common emitter point (figuratively speaking, they together "pull up" or "pull down" it so that it moves). In addition, the dynamic load "helps" them by changing its instant ohmic resistance in the same direction as the input voltages (it increases when the voltage increases and vice versa.) thus keeping up constant total resistance between the two supply rails. There is a full (100%) negative feedback; the two input base voltages and the emitter voltage change simultaneously while the collector currents and the total current do not change. As a result, the output collector voltages do not change as well.

Differential mode: in differential mode (the two input voltages change in opposite directions), the two voltage (emitter) followers oppose each other—while one of them tries to increase the voltage of the common emitter point, the other tries to decrease it (figuratively speaking, one of them "pulls up" the common point while the other "pulls down" it so that it stays immovable) and vice versa. So, the common point does not change its voltage; it behaves like a virtual ground with a magnitude determined by the common-mode input voltages. The high-resistance emitter element does not play any role—it is shunted by the other low-resistance emitter follower. There is no negative feedback, since the emitter voltage does not change at all when the input base voltages change. The common quiescent current vigorously steers between the two transistors and the output collector voltages vigorously change. The two transistors mutually ground their emitters; so, although they are common-collector stages, they actually act as common-emitter stages with maximum gain.



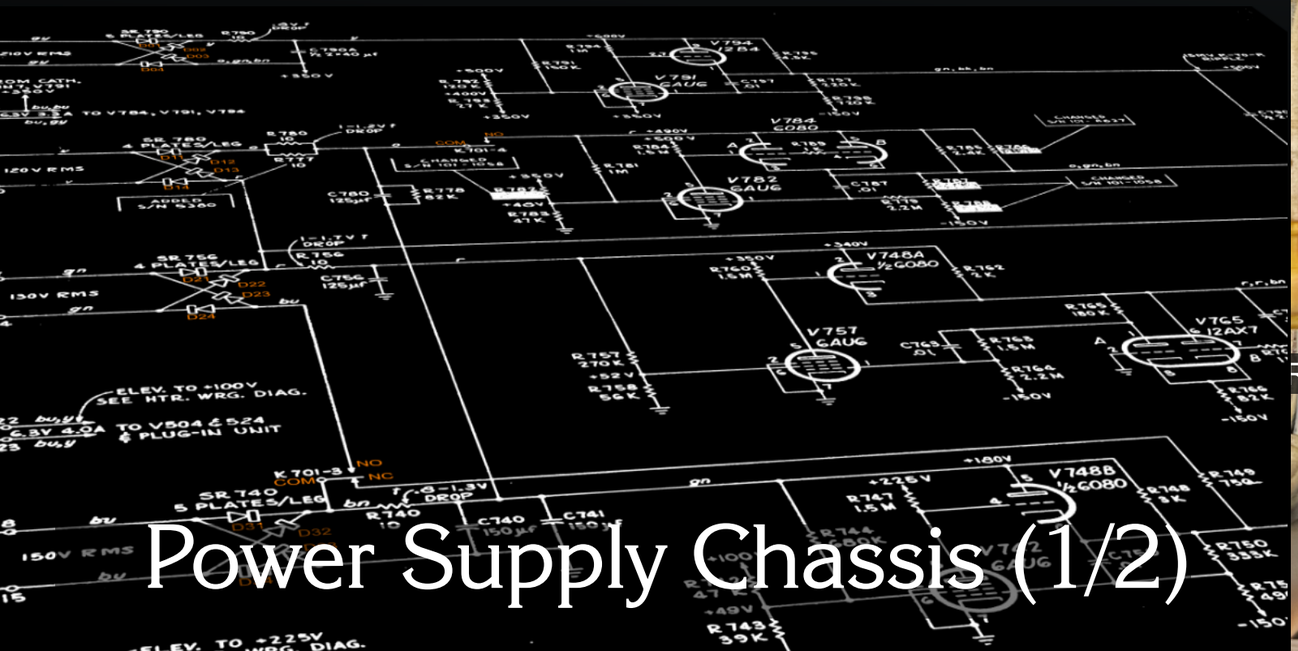
Component layouts

Every electronic equipment is defined by its electric **schematic diagram**, where each **component** is marked as a conventional **symbol**, identified by a **reference designator** (e.g., R123, V124 etc.), often with its **value** (e.g., 100K, 20nF, etc.).

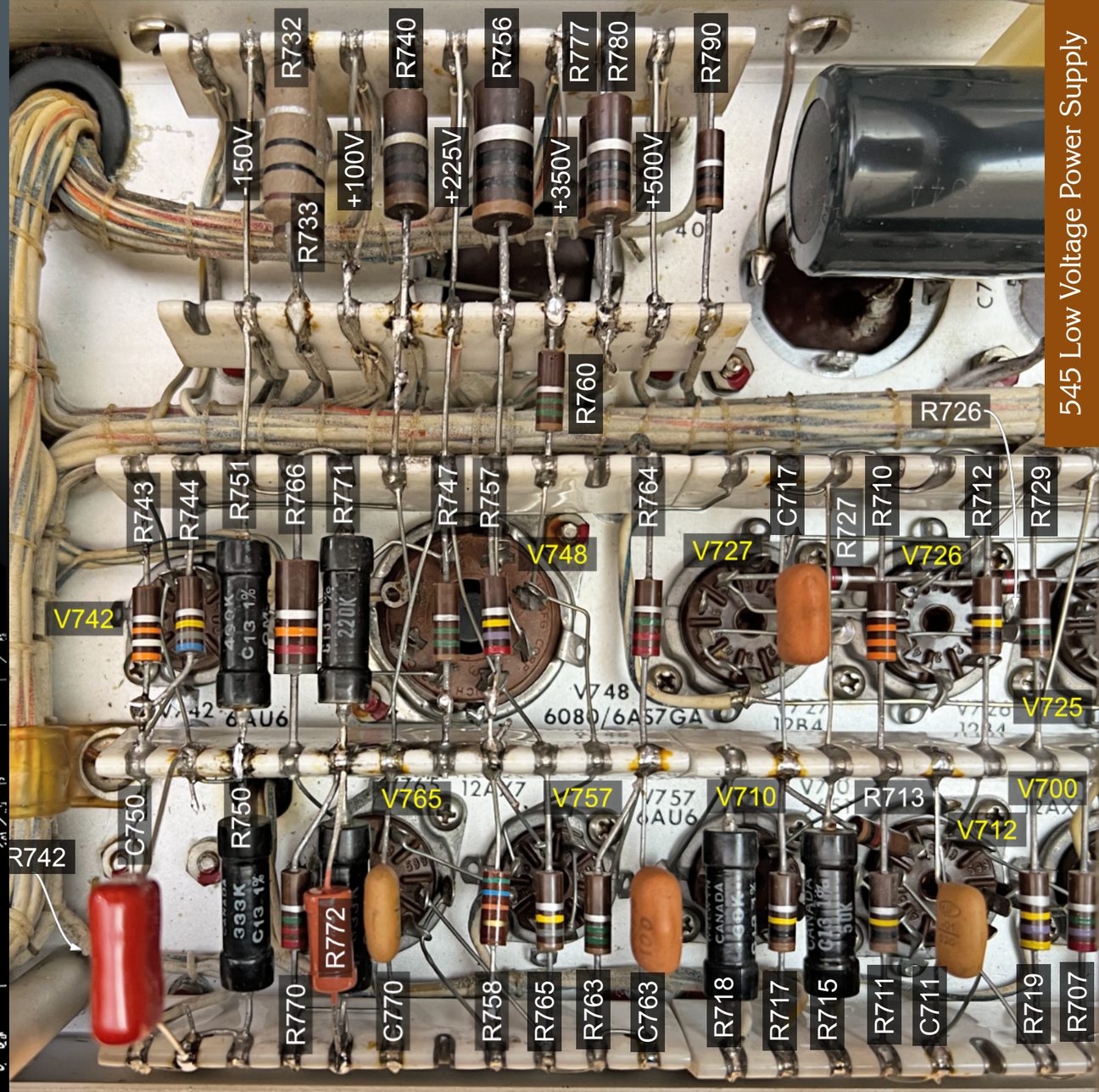
Tektronix, as we saw, has always provided us with good and complete manuals, but in the beginning, i.e., in the first years, they didn't use to supply the **components layouts**, i.e., with the physical component map.

I tried to partially remedy this problem, by providing illustrated component layouts of the main chassis composing the 545. I believe these drawing a valuable help for the restorer, which I myself now often use.

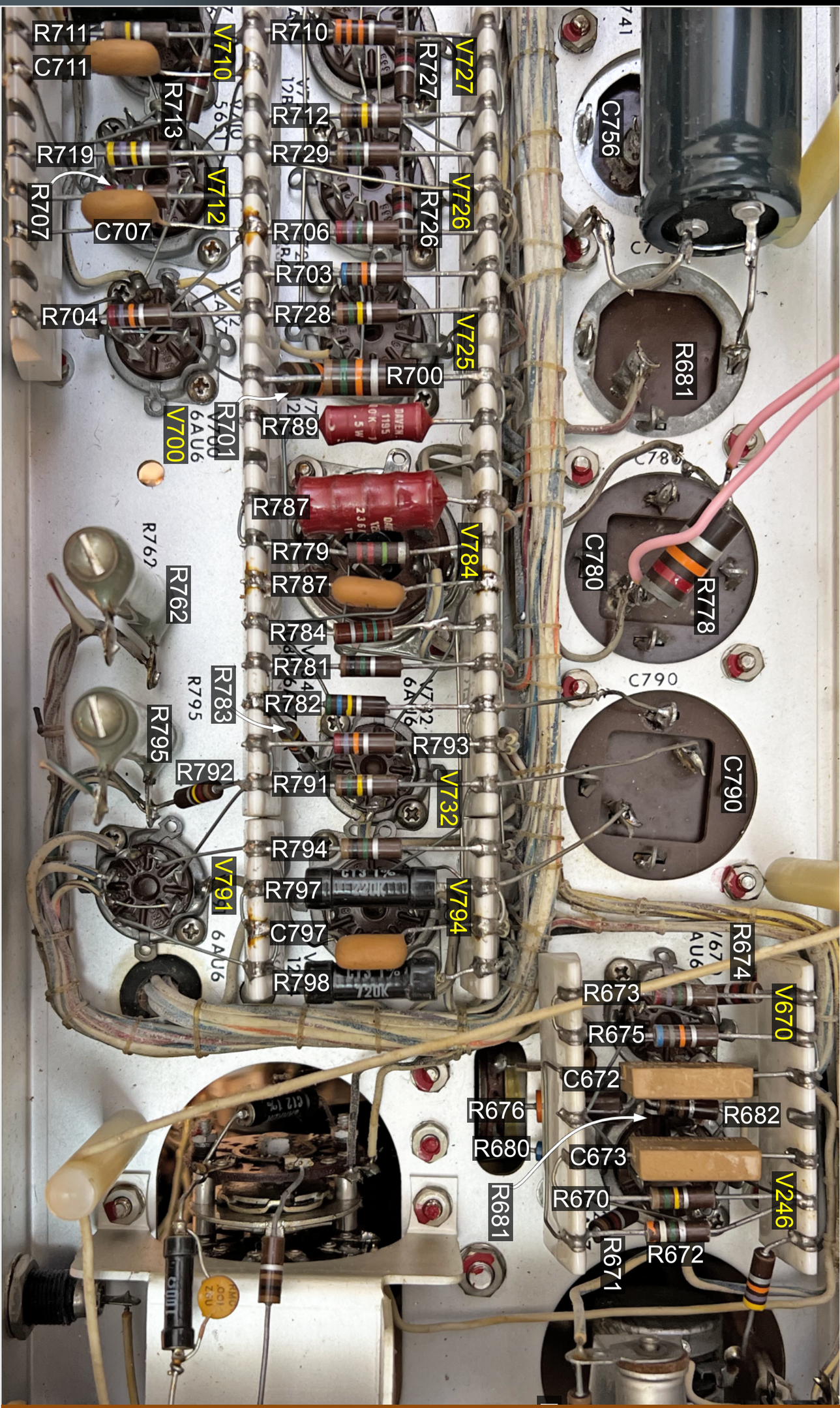
Notice: in some cases, detailed where suitable, I needed to add **in orange** some reference designators where they were not originally present in the schematic diagram. It these cases, you can find also the modified schematic diagram.



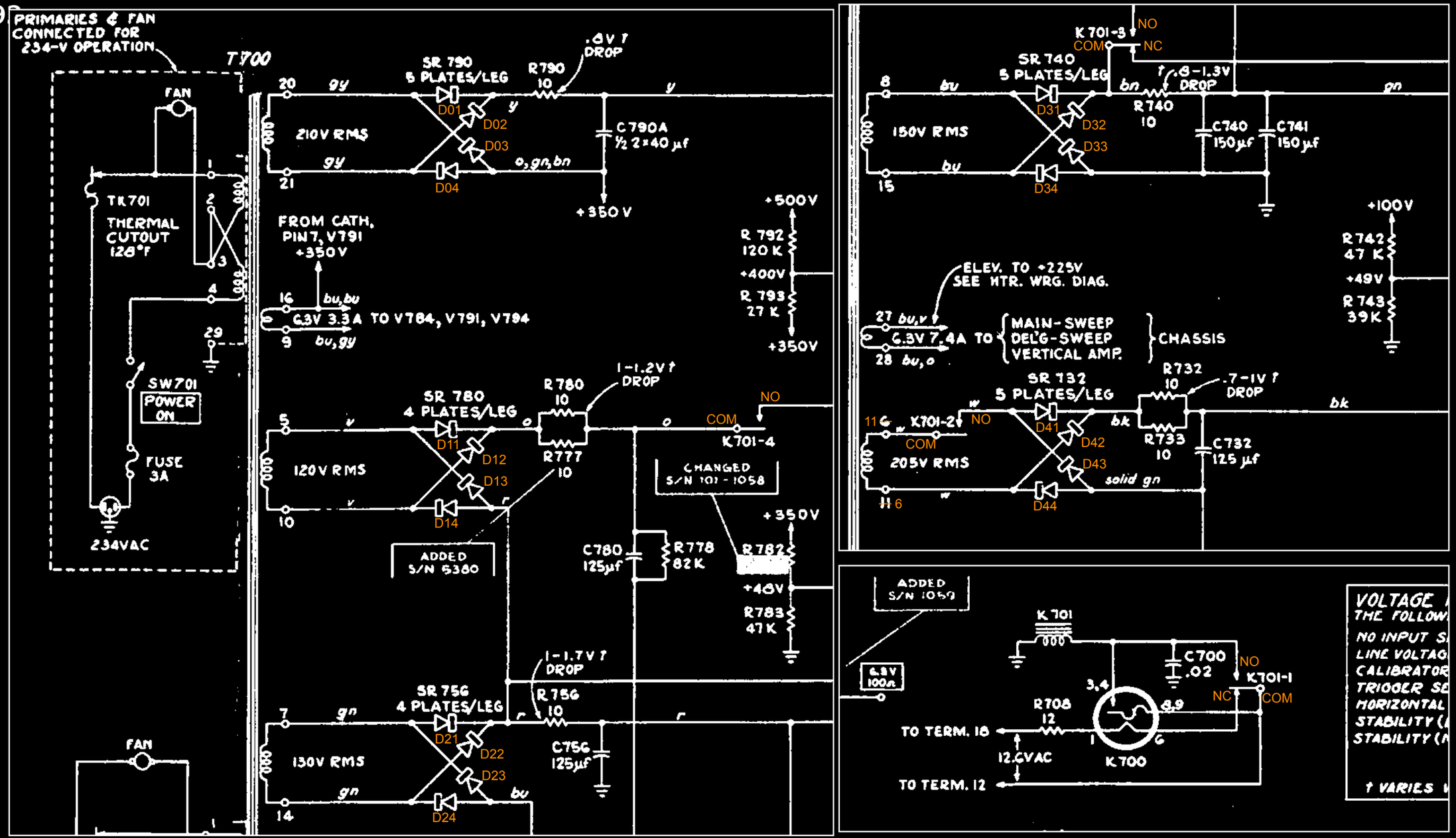
Power Supply Chassis (1/2)



Power Supply Chassis (2/2)



Added Reference Designators

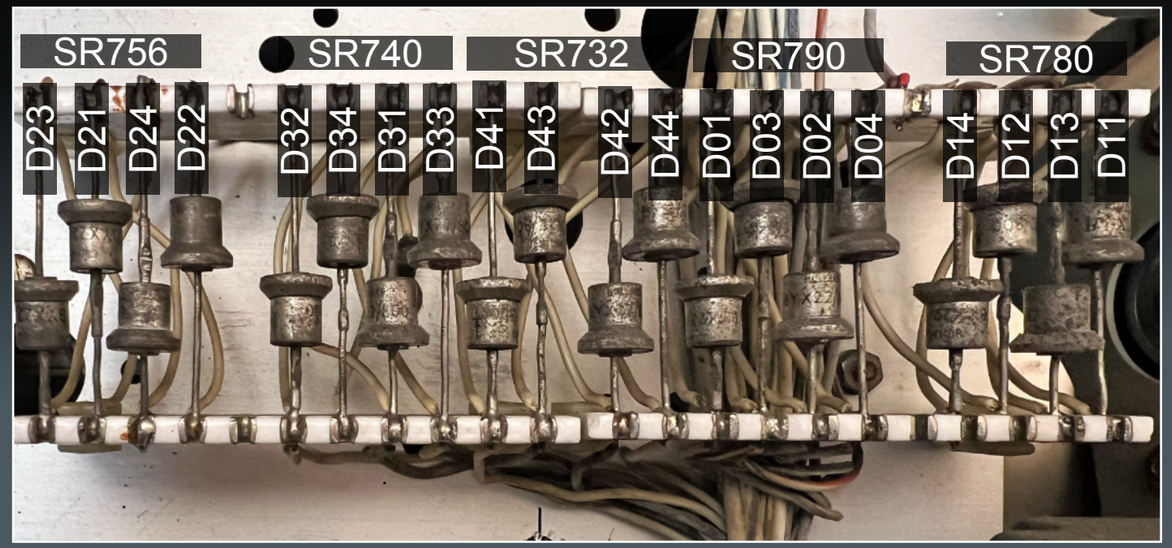


Rectifiers and relays

Rectifying diodes. Continuing my work of creating a layout documentation of the 545, I noted that the rectifying diodes have not a reference designator, because the schematic diagram in the manual is from when the 545 had selenium rectifiers (SRxxx reference designators). So I gave them a name (DR).

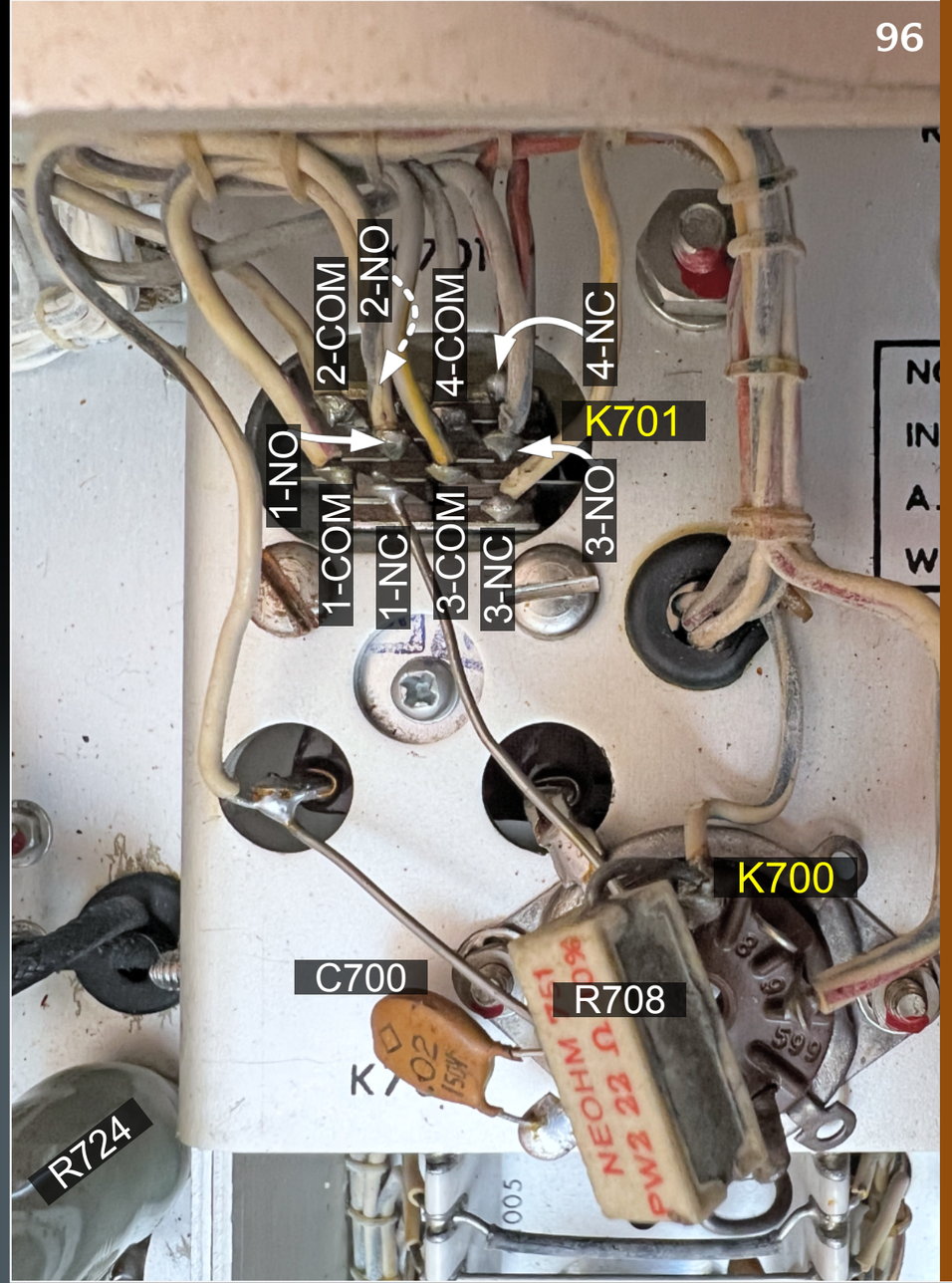
Time-Delay Relay. A thermal-delay relay, K700, delays application of high voltage to the external circuits for about 25 seconds so that the heaters have time to get up to temperature. The DC current to the heaters of the plug-in units bypasses the regulator tube, V748B, through R749 during this period. If the AC circuit is momentarily broken, the thermal-delay relay operates and again waits for 25 seconds after reapplication of the AC before completing the DC high-voltage circuit connection.

Also for the relay K701 I had to add references to its contacts (COM = common, NC = normally closed, NO = normally open) in the electric schematic diagram.



Diodes

Relay



545B's First Repair

Well, not the first ever, but the first by me. The problem is that my 545B switches on, but it cannot trigger the signal, and the CRT is blurry for the excessive jitter. All the voltages are almost good in value, but the +225V has a **giant ripple**: 10 V instead of 5 mV.

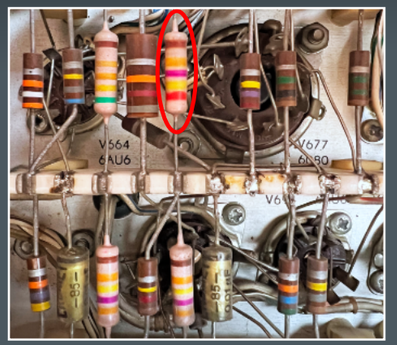
The filter capacitor has been replaced by someone else with a new one. But… look, it is not soldered! Probably the shipment broke the joint. I resolder it, and…the ripple is reduced but is still 1.5V.

I discover that I am working on a wrong schematic, downloaded from Internet, but luckily, I have the printed one (my 545B is more recent). As we noted above, for the 500-Series, Tek gave only the schematics and not the component map, making more complex the repair. I check the 6080 double power triodes that regulate the voltage with my TV-7/U tube tester, and find out that one of them if faulty. I replace it, as well as the filter capacitor, which was too small. Again, the ripple is lower (800 mV), but still in excess. At this moment, the instrument works for the photos, but now I can't help but solve the problem…

In the beginning I am deceived by the +225V **200 mA** current absorption, which seems excessive. Is the ripple due to an overload? It is easy to measure the current: every voltage has a resistor in series for this; for the +225V it is R700. It's a red herring; to discover that, I had to section all the +225V line, a long work, which finishes in nothing: the problem is not the load.

In fact, the 545, with its **20-tube** vertical amp, drains more current from the **+350V**, whose regulator has two 6080 triodes in parallel. The **545B** vertical amplifier drains by itself as much as **80 mA** from the +225V, so, in the 545B, one 6080 triode has been moved from the 350V to +225V section.

After a careful study, I finally discover the **true guilty**: a precision resistor (R681, 247K) changed its value to 295K (the resistance value increase is a typical problem in old electronic stuff). In the study, We will analyze more in detail these old power supplies next.



She is the guilty, circled in red here on the left, Why "she"? Because in Italian "Resistenza" is feminine…

Here above, the big 545B is celebrating with the the small 321A its return to life.

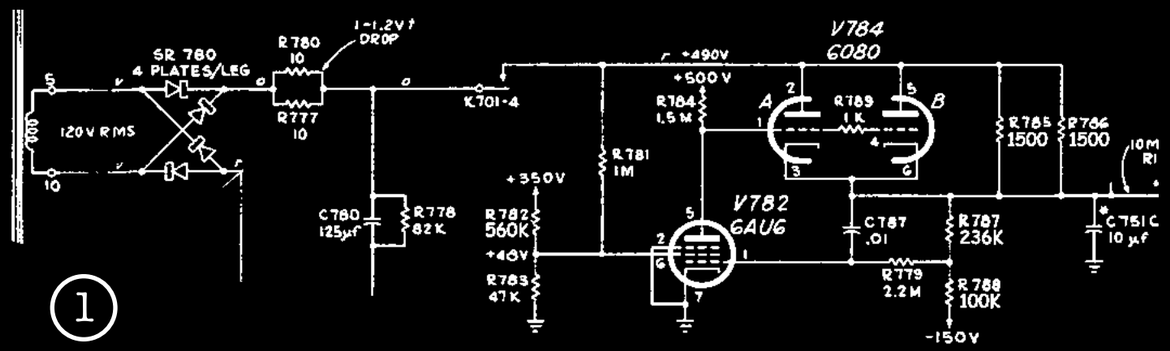
545, Fixing a Working Power Supply

Are you crazy? Why should I repair a **working** power supply? Simple: you think it is faulty, just because you didn't understand (I didn't…) how it works, as we are going to show. I believe the following notes could be useful, not only for the **545**, the current patient of our cares, but in general, for many scopes.

Let's start with the **symptoms** from which I started: excessive +350 V voltage (370 V) and excessive ripple (60 mV instead of 10). The table reports the voltages inside the 545 and their correct values. I save you the description of my many ingenuities (sorry, of the Donkey my friend), and I'll cut to the chase.

As often happens to me, I start checking the most obvious things: a good policy. But, when you cannot get results, there's no point in being stubborn as I do. You must stop and think, trying to understand all of the circuit that is giving you troubles. As I mentioned above, the circuit that we are examining is rather simple. The manuals give you a good description of it, but they don't underline its basic operation.

Basic operation



1



2

❶ Schematic diagram of the +350V power supply.

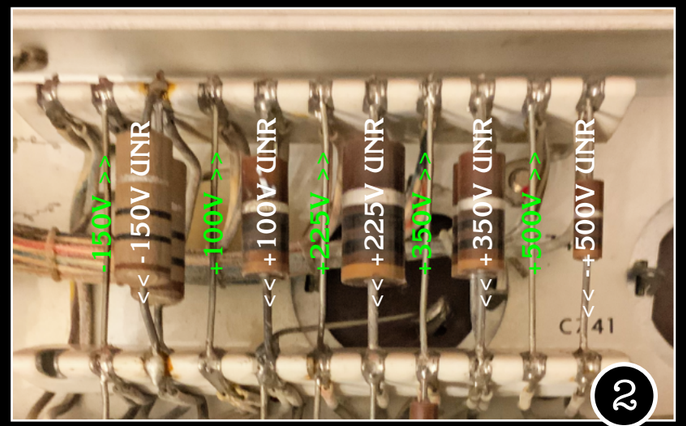
❷ 20W R85 and R786 resistors in series with the load.

❶ The battlefield reveals that victory was neither immediate nor easy… ❷ The power delivery points and the resistors used for current measurement. ❸ The table with the allowed limits for each voltage.

The 545 stabilizers (and perhaps many others) work **the other way around**. If today we all want to be "green", the 545 is definitely "red". The DC unregulated power passes through two big resistors (R785 and R786 in the schematic) before going to the load; so big that I couldn't find them initially (photo on the right). In this way, a certain voltage, lower than the nominal value, reaches the scope circuits. E.g., after the resistors, you have for example 330V instead of 350. The effect of the regulator circuit is just to use a power triode (6080 V784, in this case two in parallel), **to add** power to the load, thus **raising** the output voltage.

The 6080 is thus like a tap (in this case the name "valve" is very appropriate); when the voltage on the load is low, the tap opens, and more power flows into the load, until reaching the proper value. Then, the tap is controlled to maintain constant the voltage.

Who is the controller? Another tube, the 6AU6 pentode V782. The output voltage is sampled by a divider (R777 and R788), calculated in such a way to have about -1.7V in its midpoint when the output is exactly 350 V. This voltage is led to the grid of V782, which amplifies it and drives the grid of V784. When the output is too high, the 6080 grid is made less positive, reducing the power transfer to the load. When is too low, the 6080's grid becomes more positive, opening the tap, and the energy flows.



White labels indicate the resistors where the unregulated power is supplied to the stabilizer. Green labels show the output of the stabilizer. If necessary, these jumpers can be cut, but in that case you need a dummy load or the stabilizer will not work (see text).

Test points

If the output voltage is not exact, you could think (I though…) that the problem was in R787/R788 divider. Or, if the ripple is too high, you could think (I thought…) that the problem was in the capacitors or in an excessive load.

Measuring the current is easy: Tek designer provided definite **delivery points** (see the photo below) for every voltage, and, for each of them, series resistors to **measure the current.** They are located in the bottom part, so you have to place the scope upside down.

The 545 schematic reports these values for each voltage (R780 on previous page). Just read the voltage drop across them, and with Ohm's law you can calculate the current (in +350V case, 1-1.2V, i.e., 200-240 mA).

If the **load is too low**, e.g. for other problems in your scope, the voltage becomes very high (400 V in my case), and the poor 6080 is totally in cut-off, with the grid almost at zero. It cannot do nothing less… than doing nothing, i.e., being all open.The duty of the 6080 is just to add power to the load; if the load is too low, the voltage goes high (again, the Ohm's law). Just add a load and the regulator will start again doing its work. For the same reason, you cannot just cut the jumper to the load to test the power supply alone. You can, but you must add a dummy load, better if with a filter electrolytic capacitor in parallel, because, in 545, some of them are in the load and not in the power supply.

If you don't want to waste power, you can replace the shunting resistors with new ones of higher value, so that the voltage without the regulator tube(s) is somewhat lower than the nominal value.

Ripple canceling

We didn't mention the other side of the 6*U*A6. It is a nice trick of the Tek' designer, that used the screen grid as a second control grid, leading to it a part of the rectified unregulated input voltage (through R782/R783), to apply, in opposite phase, the ripple from the regulator and cancel it. It works very well…

	-150V	+100V	+225V	+350V	+500V
Max. output ripple	5	5	3	6	7
Output ripple (typ.)	3	5	1	6	6
Dropout (RMS line)	100	100	102	104	102
DC input voltage	95	175	330	475	600
Min DC input voltage	60	140	270	400	570
Current (typical, mA)	200	80	115-130	250-340	65-70
Input Ripple (typical)	10	7	10	16	8
Xfrms windings (RMS)	205	150	130	120	210

❸ **The table with the allowed limits for each voltage.**

Fixing a Non-Apparent Fault

After having fixed many 545's problems, I started taking the photos for the component layouts, and during this work, I discovered the situation shown in the photo here, for one of the rectifying diodes. Albeit all the checks I did on the power supply voltages, I didn't note this… An important fault was present but it didn't produce any apparent effect.

Also this can happen in an old oscilloscope…



Fixing a Faulty Power Supply

With these old traps, you can't take anything for granted. The situation can change under you feet in a short, misleading you (me…). The point at issue is again the ripple. I observed a huge ripple on the +350V line, which wasn't there before. I could determine rather soon that the ripple was originated in the +100V line (the +350V is obtained by adding 250 V to the +100V voltage). So, I fixed on this problem and analyzed one thousand times all the components and the voltages of the +100V circuit. Nothing: all was perfectly right, but a huge ripple (1.8 V) was there.

Then I noted that the voltage divider which sets the output voltage, is referred to -150V. Do you want to see that... yes, the -150V has a monster ripple of many volts. How could this happen? I had already checked it carefully... I was able to reconstruct what happened as follows:

- the -150V voltage operated correctly;
- at a certain point, its filter capacitor C732 went shorted, and I got mad for the -150V reduced to -135.
- I worked on it for some hours, but attributed the fault to the noisy adjustment trimmer;
- the voltage was again OK, and I was happy.

The faulty capacitor really changed its state from “almost shorted” to “just open”, so the regulated voltage was OK with the VOM but had a huge ripple, which you cannot see without an oscilloscope. OK, I could understand it earlier, but, um, let’s say that I wanted spend some hours in some way… um.

So I replaced also C715, and now I keep my eyes wide open, ready to check/replace other capacitors. They are really very old and perhaps are all going to die in a short. Now the situation appears stable, but, again, you can't take anything for granted, and check more times each of the supply voltages and their ripple.

Initially, I just use to disconnected the old capacitors and add new ones in some way. Later, I like to to rebuild them in their old can, so that the original look is preserved. I prefer the ones with the black paper tube protection, like those in the photo on the right, because the paper tube hides the sign of the cut.





500 Series

Subsection: The Horizontal Chain

Even when your CRT is not working, you can anyhow check many sections of your oscilloscope.



Bumblebees etc.

I wrote this part while my 545 was still not working, and it could't. The HV section was partially destroyed and at least one tube missing (other were faulty). I could find on eBay the HV transformer and the 6AU5GT missing tube.

Power supply first

Anyway, I could start checking much of the remaining before messing up with high voltages. Encouraged for (thinking) having fixed the power supply, I wanted to verify the horizontal chain, i.e., trigger, main sweep generator, and horizontal amplifier. That could be useful also for the big battle that I expected against the vertical amplifier, of which I will tell you at the right time. Should some problem be around, I could fix it in advance. Here I made my **first mistake**. I said "thinking having fixed" and not "having fixed" the power supply. As mentioned above, it was not stably repaired, so my investigations on the horizontal chain intermixed with the power supply problems, driving me mad.

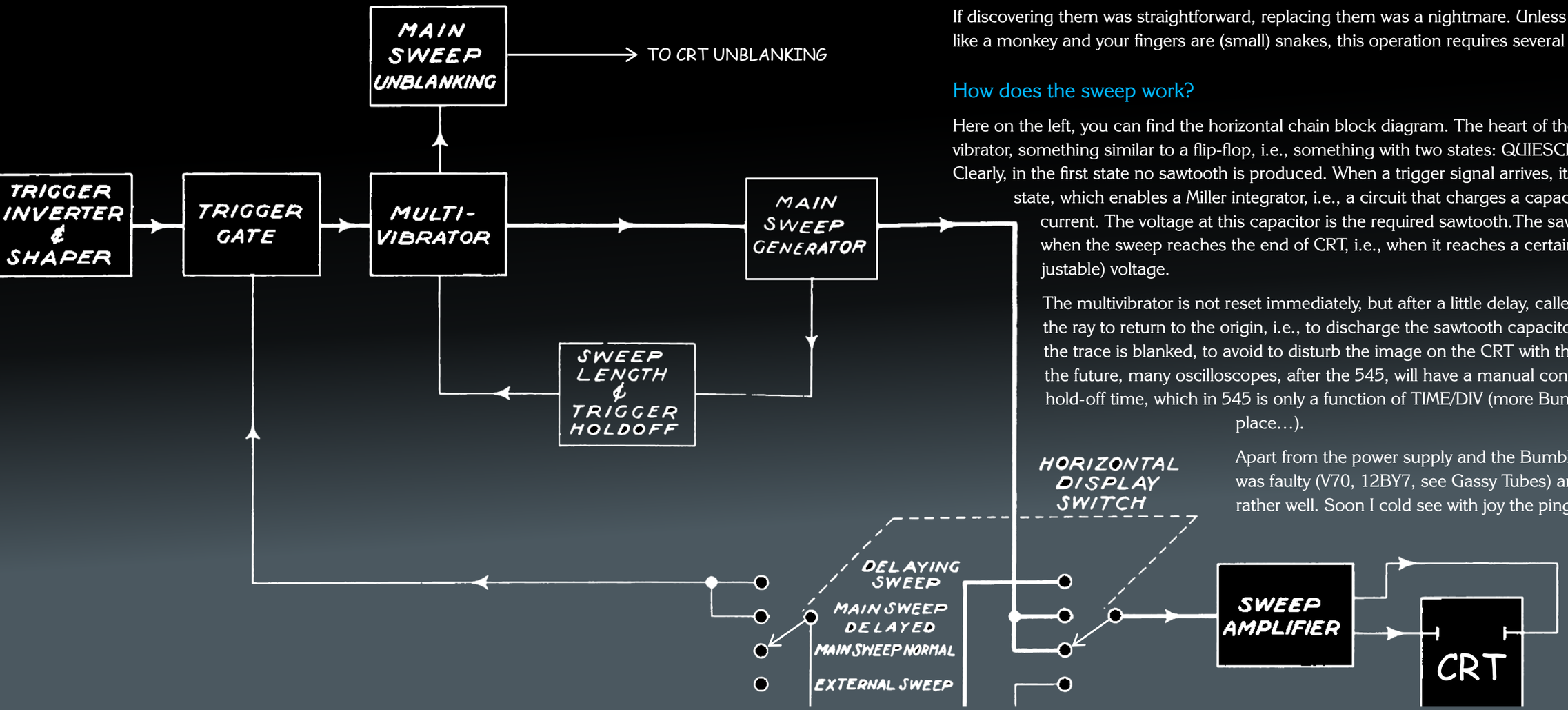
Lesson learned: never start snooping around before you are absolutely sure that the all the power supply voltages are OK, both in value and ripple, and let them on for some time to be sure that they are stable.

Fixing the main sweep

Let's start with another "lesson learned": when you see the so-said **bumblebee** capacitors (those in the photo on the right, shoot first, then ask who it is; in other words, replace them immediately. My 545 had all of them faulty.

Apart from the power supply problems described above, checking the horizontal chain was rather straightforward. The investigation started …from the beginning, i.e. from the trigger. The vertical amplifier was still out of order and thus couldn't produce a trigger signal. So, I used the external trigger input for my tests.

Checking the Horizontal Chain



Soon I discovered that the right signal arrived to CRT's deflection plates, and soon I discovered that it disappeared rotating the TIME/DIV knob below 100 us/div.

Something was happening, that anyway I expected. Some of the time base capacitors were gone. As anticipated, they were of the infamous kind said **bumblebee**. As I told you, in my 545, all of them were faulty.

If discovering them was straightforward, replacing them was a nightmare. Unless you have four hands like a monkey and your fingers are (small) snakes, this operation requires several hours.

How does the sweep work?

Here on the left, you can find the horizontal chain block diagram. The heart of the circuit is the multivibrator, something similar to a flip-flop, i.e., something with two states: QUIESCENT and ACTIVE. Clearly, in the first state no sawtooth is produced. When a trigger signal arrives, it goes in the ACTIVE state, which enables a Miller integrator, i.e., a circuit that charges a capacitor with a constant current. The voltage at this capacitor is the required sawtooth.The sawtooth terminates when the sweep reaches the end of CRT, i.e., when it reaches a certain fixed (but adjustable) voltage.

The multivibrator is not reset immediately, but after a little delay, called **hold-off,** to allow the ray to return to the origin, i.e., to discharge the sawtooth capacitor. During this time, the trace is blanked, to avoid to disturb the image on the CRT with the back going ray. In the future, many oscilloscopes, after the 545, will have a manual control to increase the hold-off time, which in 545 is only a function of TIME/DIV (more Bumblebees to replace…).

Apart from the power supply and the Bumblebees, only a tube was faulty (V70, 12BY7, see Gassy Tubes) and everything went rather well. Soon I cold see with joy the ping-pong of the two neon lamps above the CRT. But the battle was not over. Definitely.

Sweep Switches

Theory and Practice

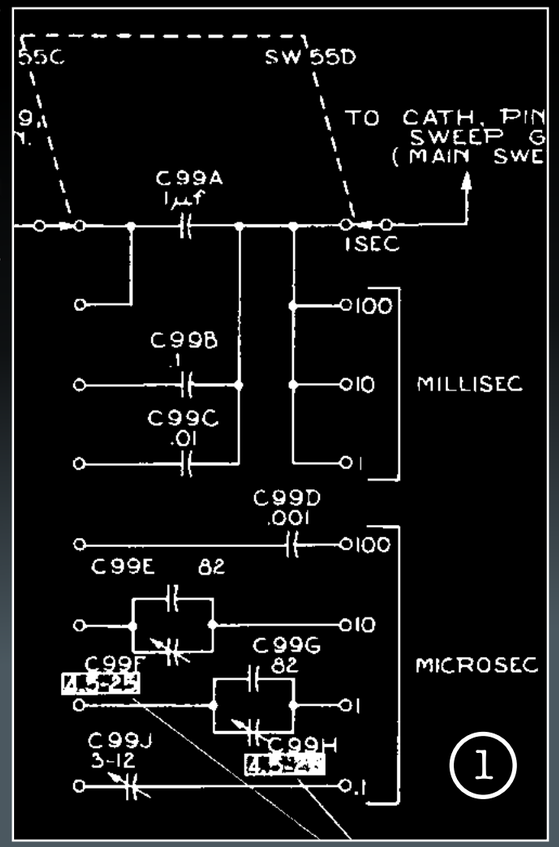
One of the things i like when working on this old stuff, is the continuous swinging between theory (sitting) and practice (standing); the former when you need to understand the problem, the latter when you must really do the repair. Much better than writing software, when you remain always sitting and destroy your brain. In the case of main sweep, practice prevailed on theory, and most of the work was replacing the Bumblebees.

TIME/CM switches

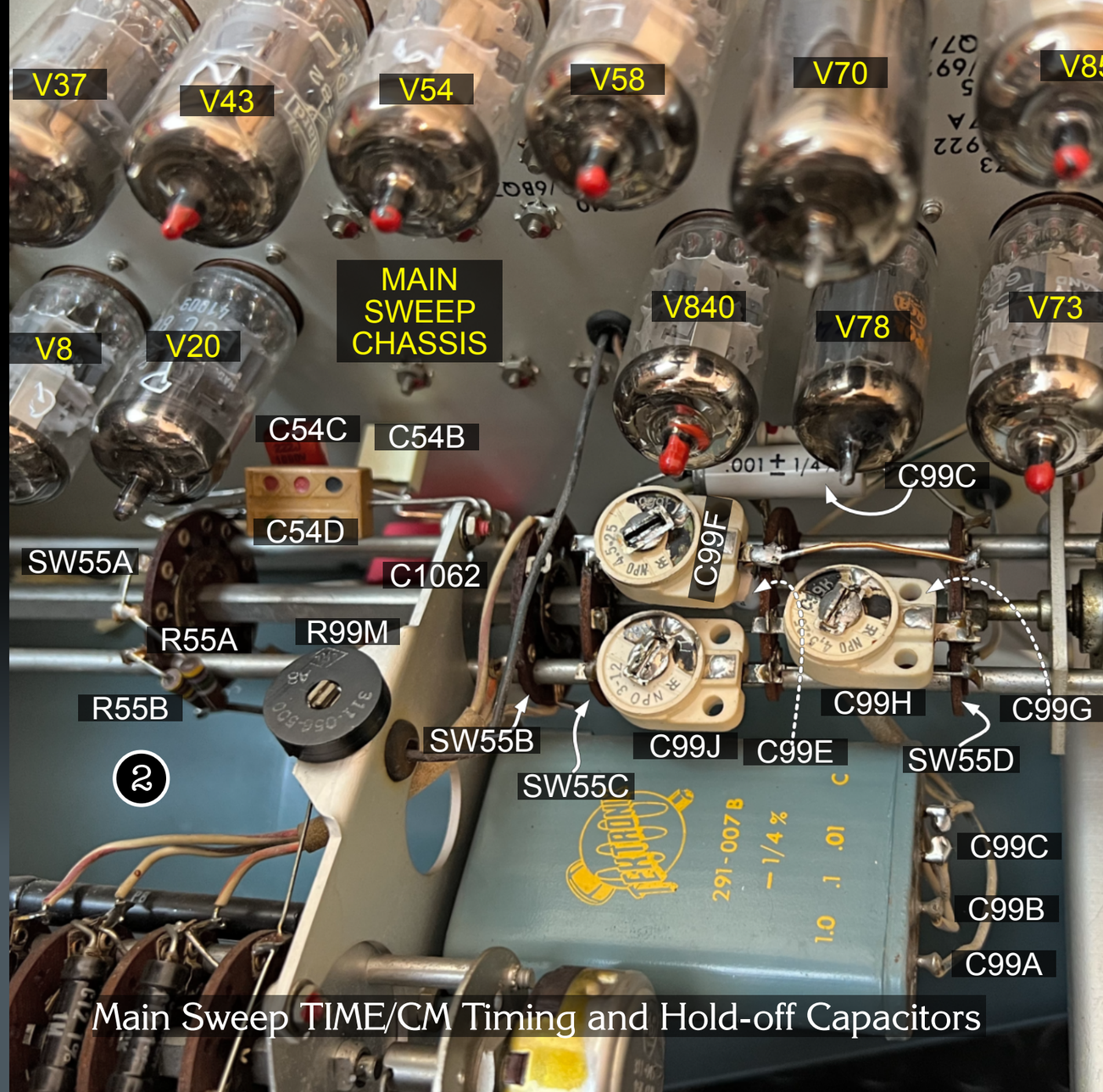
First, you need to know your enemies, i.e. the panel switches:

- **Main Sweep TIME/CM**: it switches only the capacitor used by the Miller Integrator to produce its sawtooth (timing capacitor);
- **Main Sweep Multiplier:** it switches the resistor used by the Miller Integrator to produce its sawtooth (timing resistor);
- **Delaying Sweep TIME/CM**: it switches both the capacitor and the resistor used by the Miller Integrator to produce its sawtooth (hold-off capacitor).

TIME/CM switches (i.e., the first and the third of the above list), switch at the same time the hold-off capacitor as well.



❶ TIME/CM switch schematic diagram (Miller integrator capacitors section)
❷ The TIME/CM components layout.

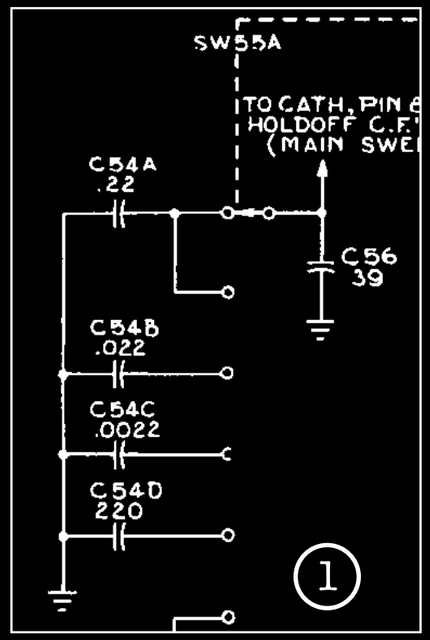


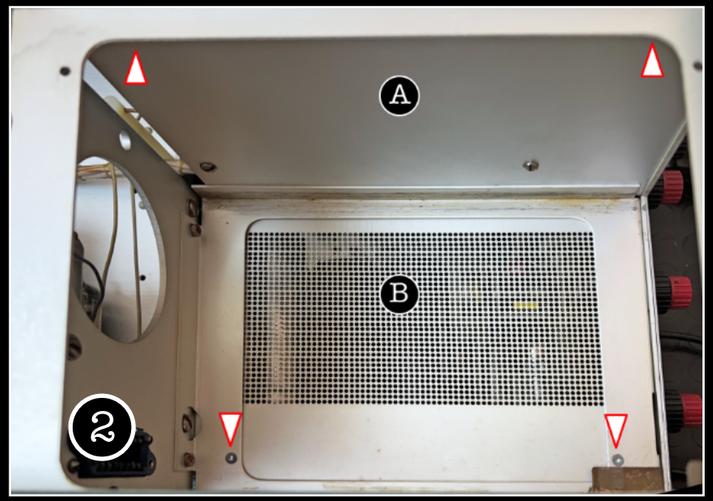
Main Sweep TIME/CM Timing and Hold-off Capacitors

Even if also carbon resistors change (raising) their value over time, we are now more interested in capacitors. As shown here on the right, the Main Sweep uses 9 of them. They have all same reference designator numbers, but are different components, with the exception C99-A-B-C, all in the same can. I thought that this was probably the bad one; all the capacitor in this section were on the contrary good.

The problems, i.e., the Bumblebees' nest, were in the hold-off section, and more precisely in C54A, C54B and C54C, while C54D was good, as the other capacitors of that type (see the photo).

Replacing C54B and C is difficult, but C54A is barely possible. To reach it, you must access it from the plug-in compartment. Remove the two bulkheads A and B, by removing the four screws marked with the arrow in the photo below; it is not too difficult and make things with the capacitor much better (but much of patience is required).





❶ The TIME/CM switch, hold-off section schematic diagram.
❷ Accessing some of the Bumblebees is possible only by the plug-in compartment, by removing the metal sheet dividers. To get the part A out, it is advisable to turn it about 90 degrees anti-clockwise.
❸ The Bumblebee have been replaced by modern capacitors in this photo.

Main Sweep TIME/CM Hold-off Capacitors

3

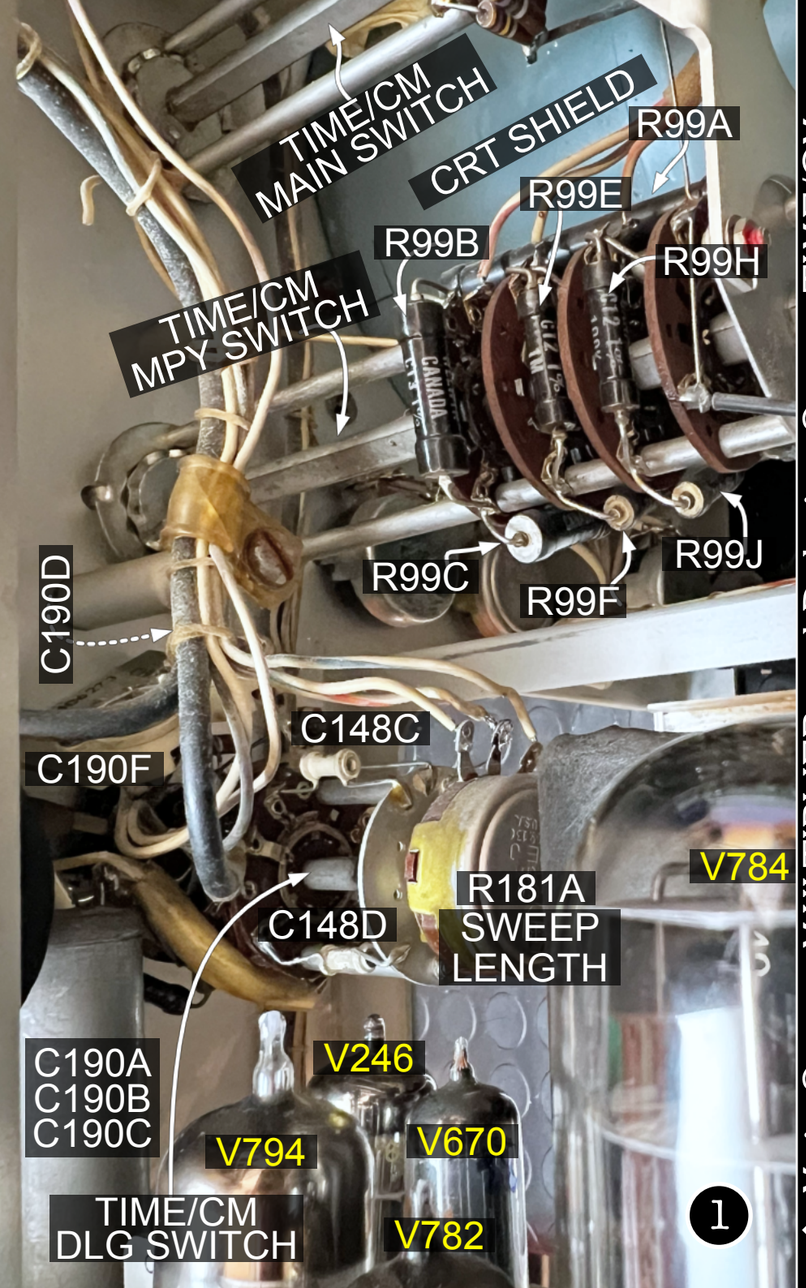
Components layouts

Used to other Tektronix oscilloscopes, I got mad on the 545 for the lack of the components layouts, normally available for the more modern models. For this reason, I decided to create my own for the areas I was working on. Then I thought it could be helpful for the other crazy people like me, and decided to document most of of this splendid oscilloscope.

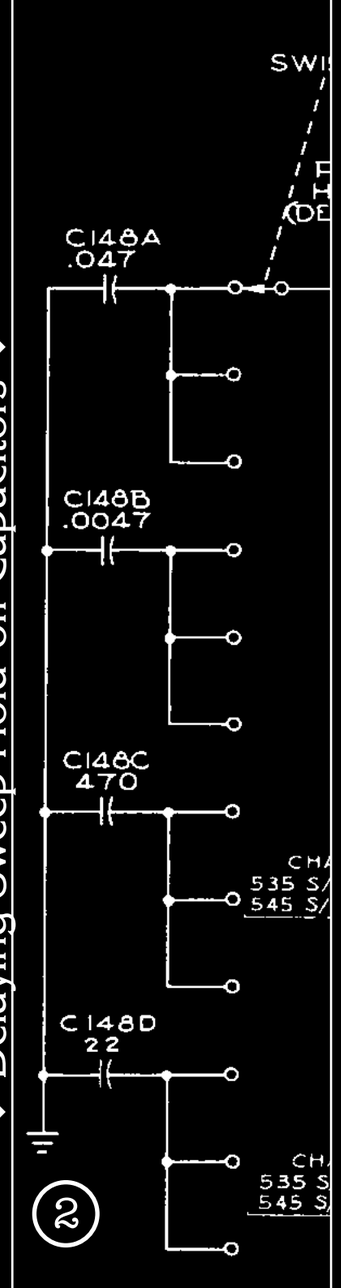
Delaying Sweep Generator, TIME/CM

To complete the story of my restoration, I report here also the TIME/CM switch component layout for the delaying sweep. This also had Bumblebees and these also were faulty.

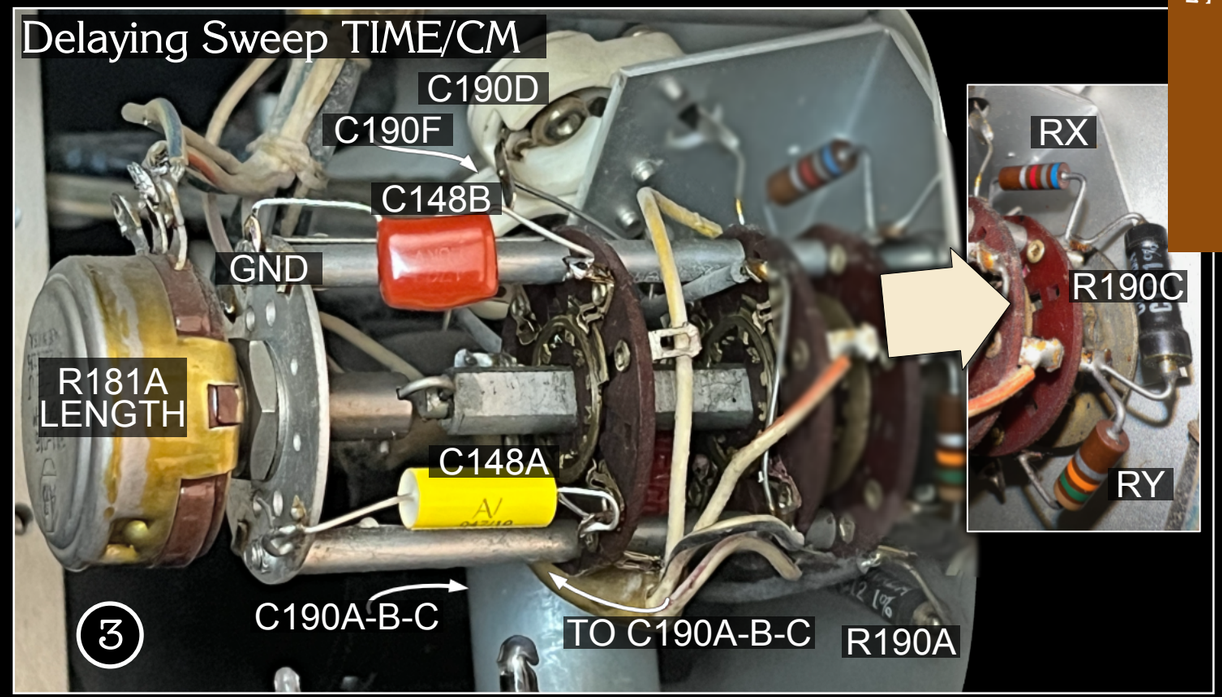
❶ Switches' landscape
❷ The hold-off capacitors of the delaying sweep
❸ Delaying sweep TIME/CM switch components layout - seen from the plug-in compartment

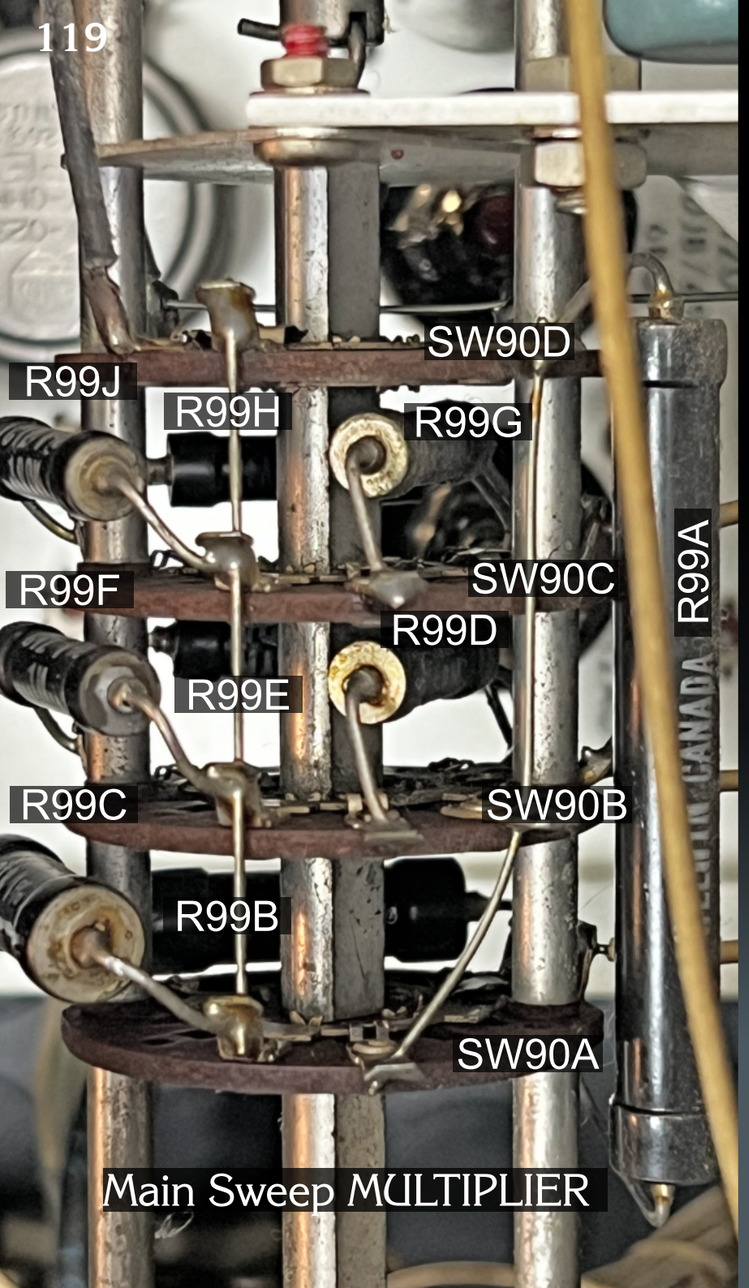


↑ Main Sweep MULTIPLIER and Delaying Sweep TIME/CM ↓



↓ Delaying Sweep Hold-off Capacitors ↓



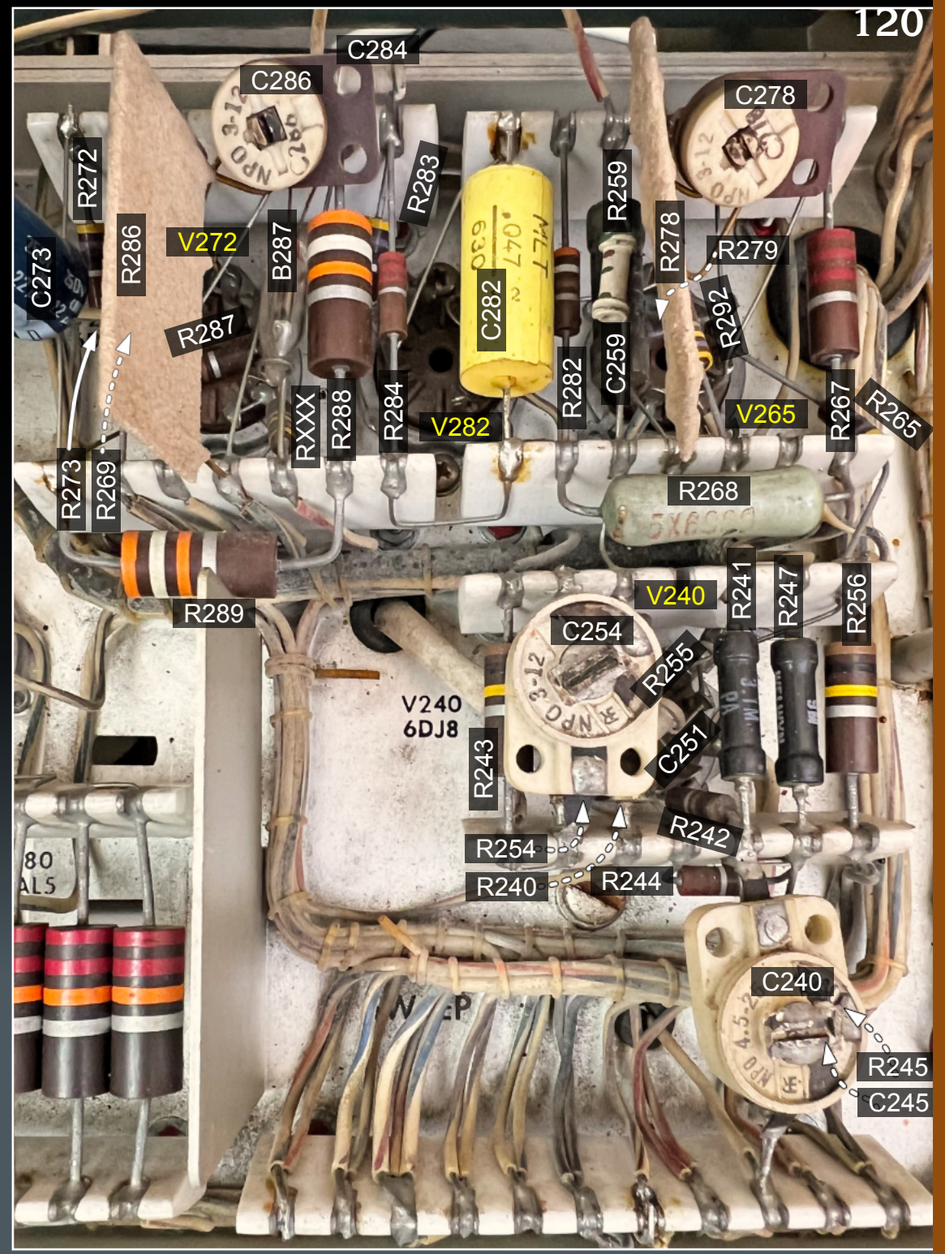


The next battle front

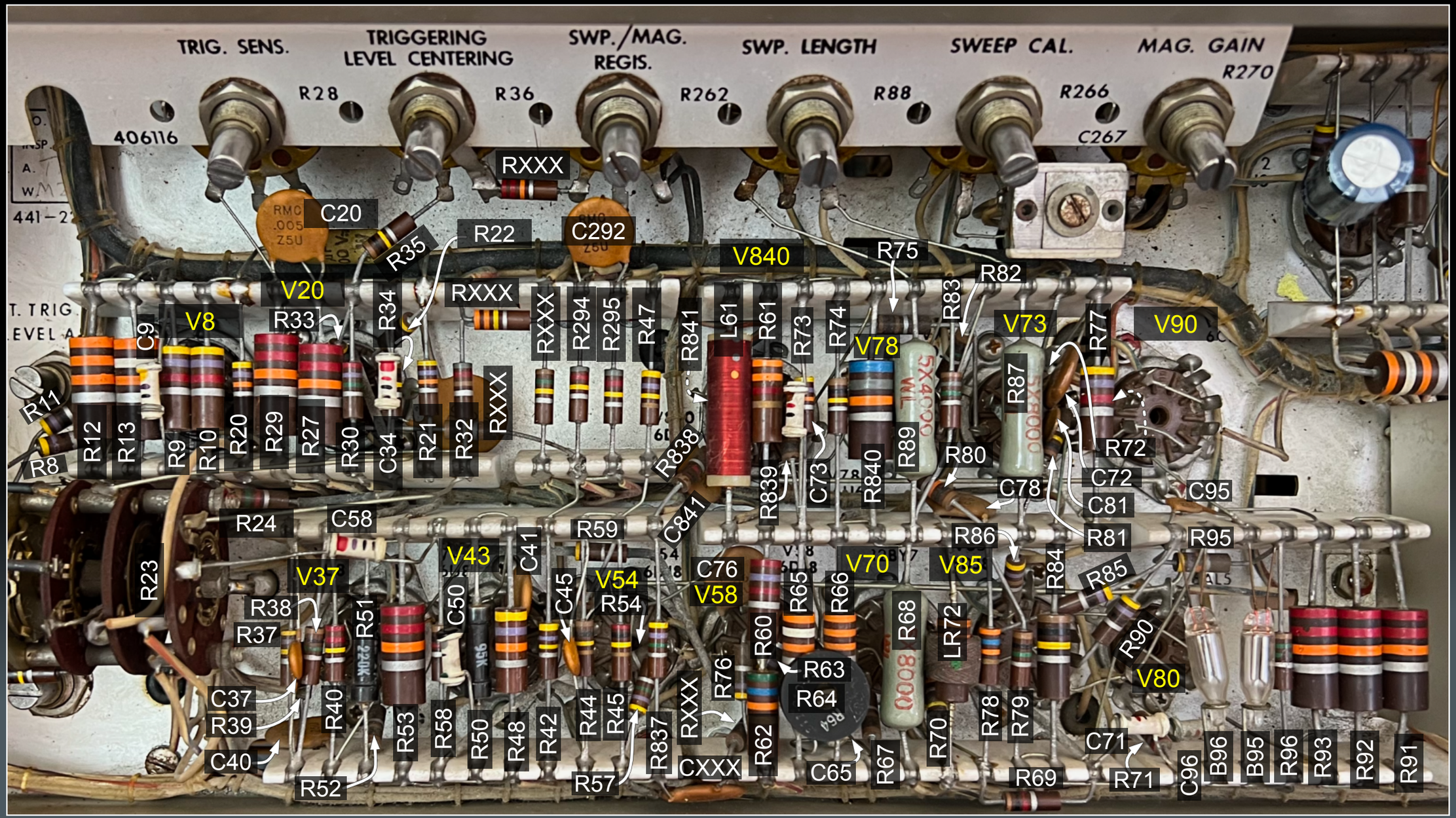
I was optimistic and expected an easy victory also with the Delaying Sweep Generator (DSG), but it was not a walk in the park. So, I had to study more deeply the circuit, to arrive to unexpected conclusions; something like a thriller, where the the killer was not the butler. Anyhow, I found the sweep generator's study very intriguing, and I don't regret having been forced to this analysis. The DSG is a little simpler than the Main Sweep, and what we say for one is good for both (and many other scopes, like the 515A and the 3B3 561's plug-in).

Anyhow, the Delaying Sweep battle had to be postponed, because I decided to try first to fix the High Voltage section. Fixing a blind scope is not as amusing as I would, and I would know if the 545 really could be resurrected. So, differently from the main sweep, I tried to fix the DSG when the CRT was already up and running. A big help. yes, but it was a harsh battle, as we are going to see.

Sweep Amplifier Chassis



Main Sweep Chassis



The Delaying Sweep Generator

The missing trigger

Before entering in the circuit's behavior, let's say that to have a sweep we need someone who triggers it. By studying the circuit, I could not understand how the trigger pulse arrived to the DSG, up to discovering that… it does not arrive there! The manual states: "*This delaying sweep can only be triggered by applying a trigger to the TRIGGER connector near the delaying sweep controls. This trigger signal can be obtained from an external source or a test lead can be connected from the TRIGGER connector to the VERT. SIG. OUT connector to trigger the delaying sweep on the vertical signal. The SLOPE, +, -, switch selects the desired slope and the ATTEN X10 toggle switch provides attenuation if desired. Other triggering adjustments operate the same as for the main sweep.*" That made me to discover the purpose of the short cable shown in the photo on the right, which arrived with the oscilloscope. This limit is removed in the 545B, which does not have this problem.

Studying the circuit

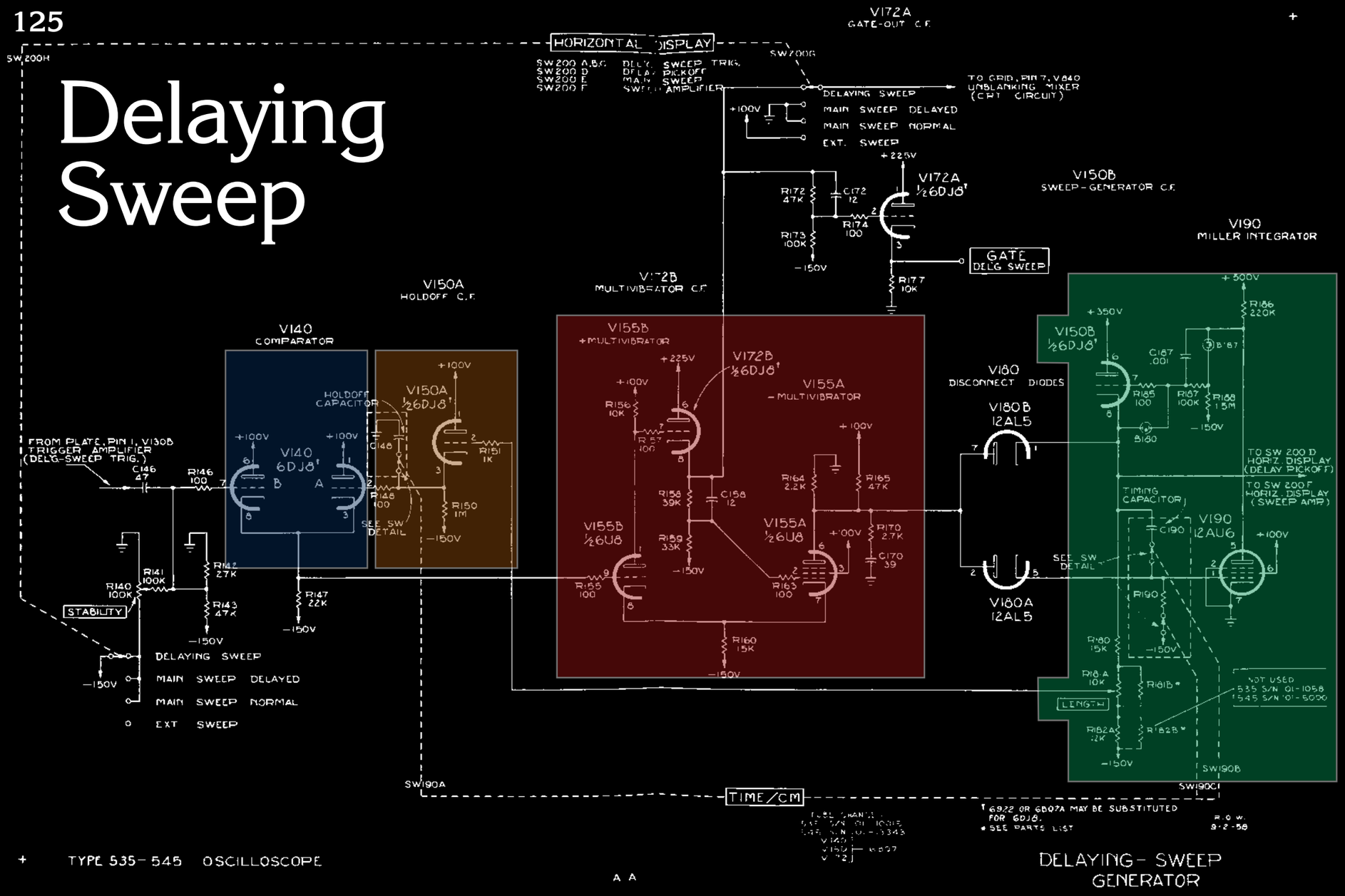
Let's start examining the schematic diagram of this part of the instrument, that, as I said, I found very interesting. The first trigger stages up to V140B grid were working rather well in my case, so I focused on the sweep generator itself. Forget for now the trigger gate, involved in the delaying switch operation.

So I had the trigger signal, and I followed it till V140B, but it stopped there. Its output (on the cathode) was absent. After a minimal study, I understood that… I had to go deeper in the circuit operation if I want ed to go further.

V140 is a classical differential amplifier, used as a comparator, but here is acting like a logical gate. It allows trigger pulses to pass from the input (grid) to the output (cathode), when enabled by V150A, as we are going to explain.



Delaying Sweep



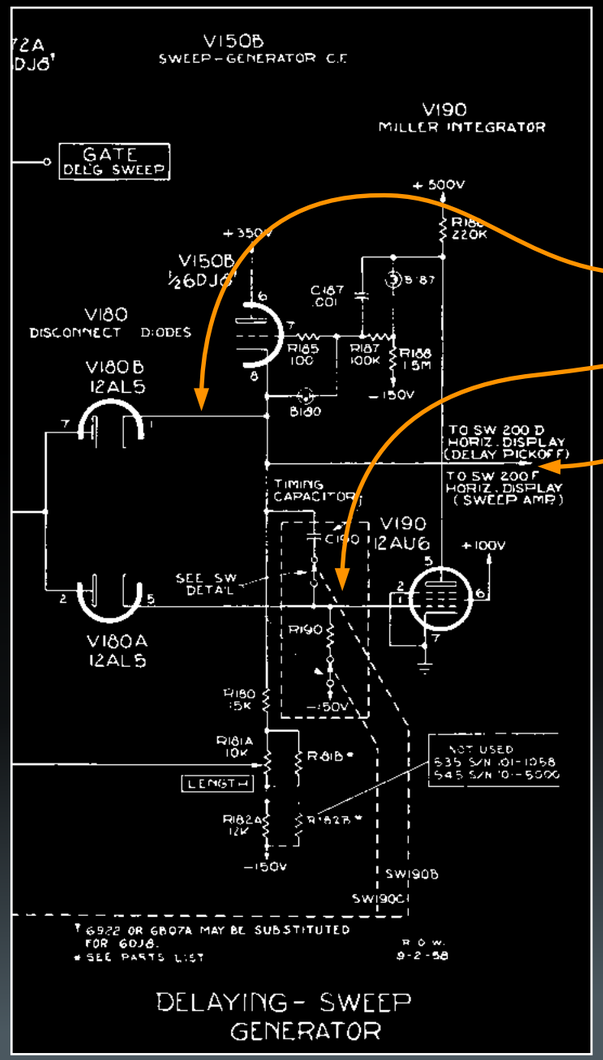
The multivibrator. V155, together with V172B, compose a classic multivibrator, a thing with two stable states. Normally, V155B is on (conducts) and V155 is open (cut-off). A trigger pulse from V140 makes the multivibrator to change its state: V155B gets open and V155A closes. The plate of V155A is the flag-waver which starts the **Miller integrator** run-up, producing the sawtooth.

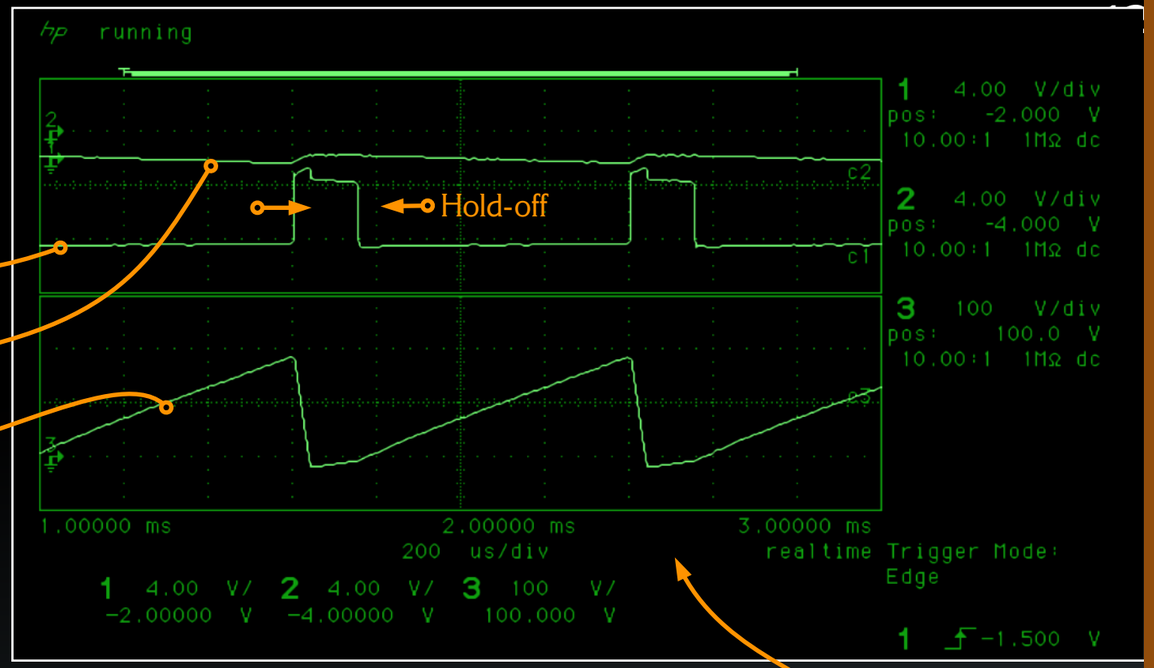
The **disconnect diodes** seem rather mysterious, but act simply like two switches. When the multivibrator is quiescent, they prevent the sawtooth generation; when is active, it frees the integrator which can start doing its job.

The Miller integrator. V190 is called “the Miller tube” and is simply a class-A amplifier with a high gain (200). Imagine the circuit without V180A. R190 resistor would merely charge C190 to a -150V negative voltage. The purpose of all the other components, is to create a **negative feedback** which opposes the voltage variation of the grid to, keeping it stable, through C190 capacitor. In which way? When the capacitor starts charging, the grid becomes more negative, and in consequence the flow of electrons in the tube reduces; V190 conducts less, and the plate then raises. But the circuit has a large gain, so the small change in the grid potential becomes a large change in the plate voltage, applied to the grid via C190. The poor’s grid aspiration for change is thwarted, and, and despite the efforts or R190, the grid voltage remains stable. As a consequence, the current in C190 is held constant, and the voltage on the cathode of V150B is an almost perfect sawtooth.

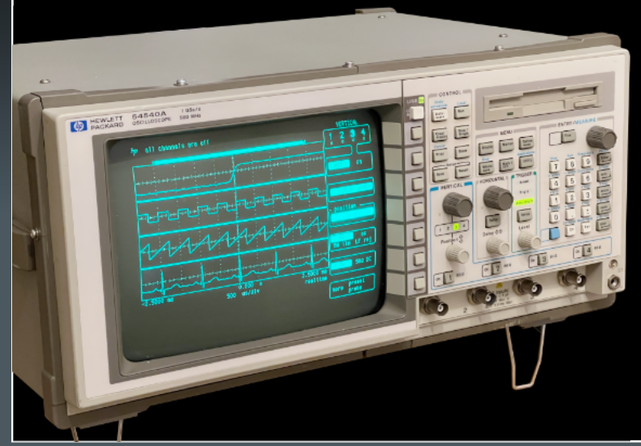
The cathode follower. C190 is not driven directly by V190's plate, but thru V150B cathode follower. Its grid is connected to the plate of Miller tube V90 through neon glow tube B95. The grid of V150B therefore follows the plate changes of V190 but remains 55 volts below the plate.

More about the disconnect diodes. In the quiescent state between sweeps, the plates of diodes V180A and V180B rest at -3.2 V. Very little current flows through V80A to the grid circuit of V90, and V90 grid therefore rests at about -3.3 V. More current flows through V80B so that its cathode is at about -5 V. When the multivibrator goes active, it lowers the diodes plates below their cathodes, and they no longer conduct. The Miller-tube grid, and plate-coupling cathode follower, are thus released to seek their own voltage levels. I.e., in the active state, the diodes it's as if they weren't there.



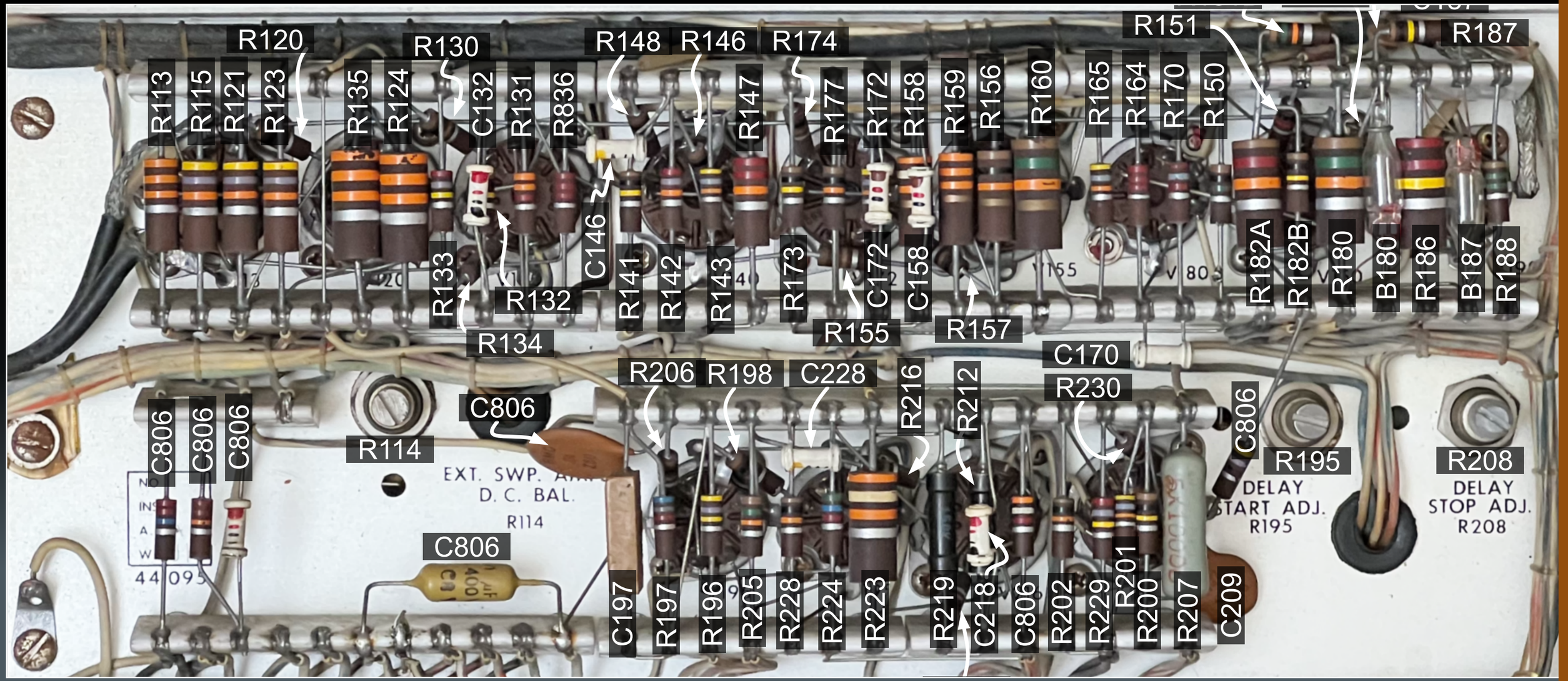


Horror! An HP oscilloscope?



Well.. I admit… for some strange perversion… well, I love it! Maybe because it is the best horse in my stable, maybe because it has four traces, maybe because it is very easy to use and can produce screenshots on floppy disk… Not the least, because I like Hewlett-Packard. Not as much as Tektronix, obviously, but the old, "true" HP produced wonderful instruments like signal generators, spectrum analyzers and much more. In my book "The Great Hewlett Packard" you can find many of them.

Delaying Sweep Chassis



The Murder(s)

Hey, we had to put up with this whole description, and still we don't know the murder's name! Well, the reason is that for two times I thought I solved the problem, and at least one of them failed. So, for two times I studied this circuit in detail, checking every single component and straining my brain to the max (this is the true reason why I could go so deep in this analysis).

The first problem: it doesn't work

The first murder… was not a murder. In this case, the problem was that the Delaying Sweep was **not working at all**. I am ashamed: after hours, I could note that the 12AL5 tube V180 (the disconnect diodes) was cold. I could soon understand that V180 and V190' filaments are not powered, unless you put a vertical plug-in in its bay. That is part of the fact that some filaments are elevated to an higher voltage, probably to reduce the difference between cathode and filament.

The second problem: non-linearity and instability

Howsoever, a murder was around, and trapping it was not easy. In this case, the problem was a **giant non-linearity** of the delaying sweep, associated with heavy instability. After uncountable tests, I decided to swap V155 (6AU8) with another 6AU8 (V228). Now the sweep stopped at all: no ramp, the trace was stuck on the first right point of the CRT.

Incredible: probably V228 was faulty. SO I checked it with Francesco's TV-7A. It is perfect, even from the gas point of view. I try again with the original tube: the scope is again working in its bad way. I swap the tubes again, and again it does't work. I check the circuit, and I note that both V155A and V155B are open (not conducting). Mhhhh… Oh dear… the tube is cold. New swap, again it works and the tube is on. So I had two good tubes, one working and the other not. I suspect the socket, and …I guessed it! Pin 4 of the socket was having a not perfect contact. I tight it, and the both tubes work now. The linearity got much better but not perfect with the original tube, but became almost perfect with the ex-V228. Luckily, the old V155 works well in V228 position, so… we are all happy now, V155, V228 and me. The 545 is again almost an oscilloscope.

Lesson learned

Never forget, as I did, that tubes have a filament!



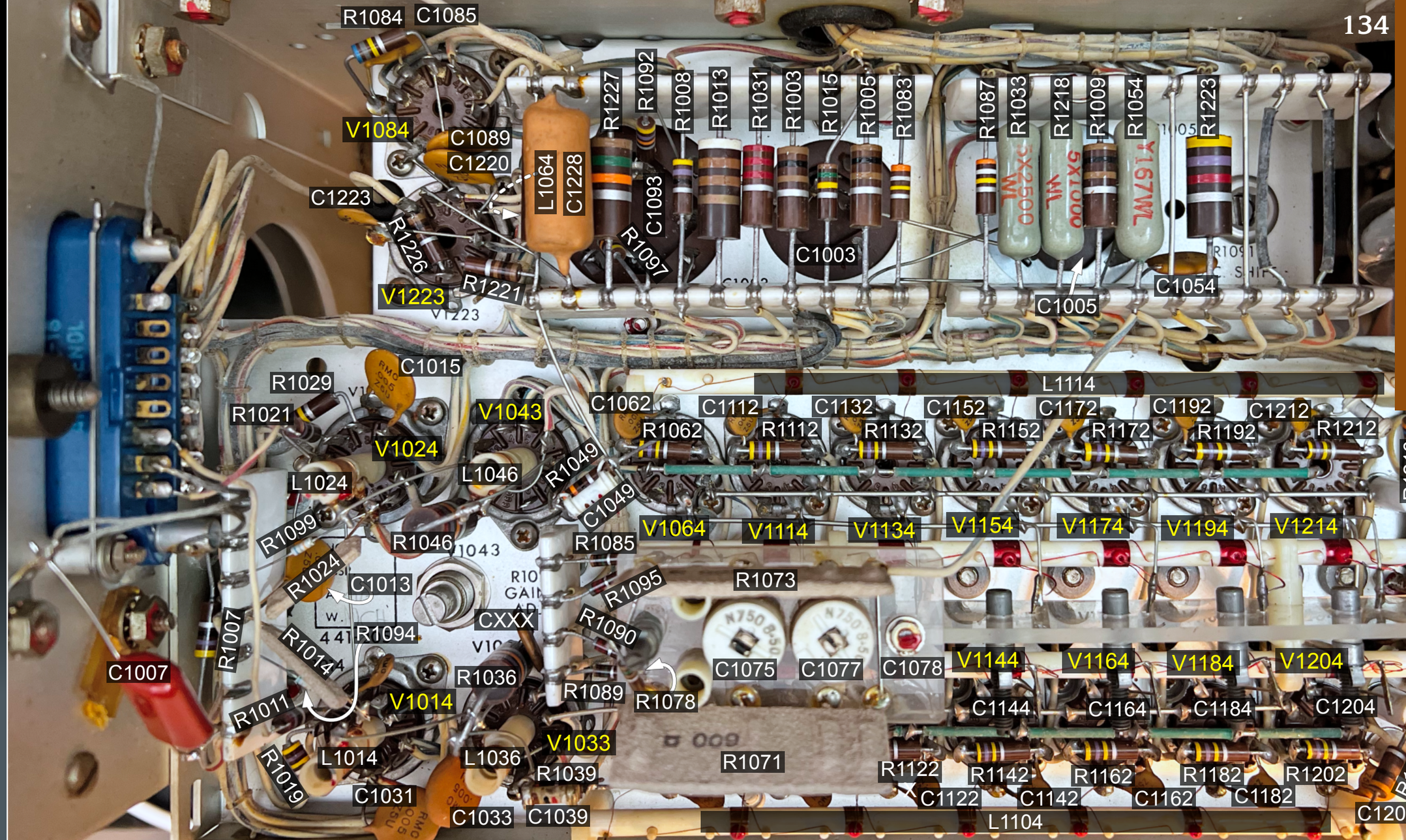
Resurrected

My marvelous 545 is a scope again. Perhaps still not perfect… but a scope!

Note the highlighted trace portion of the delaying sweep and the probably original jumper cable, described in the text, required to connect the Delaying Sweep trigger to the vertical output.

A Tek's incomprehensible forgetfulness, that will be remedied in 545B.

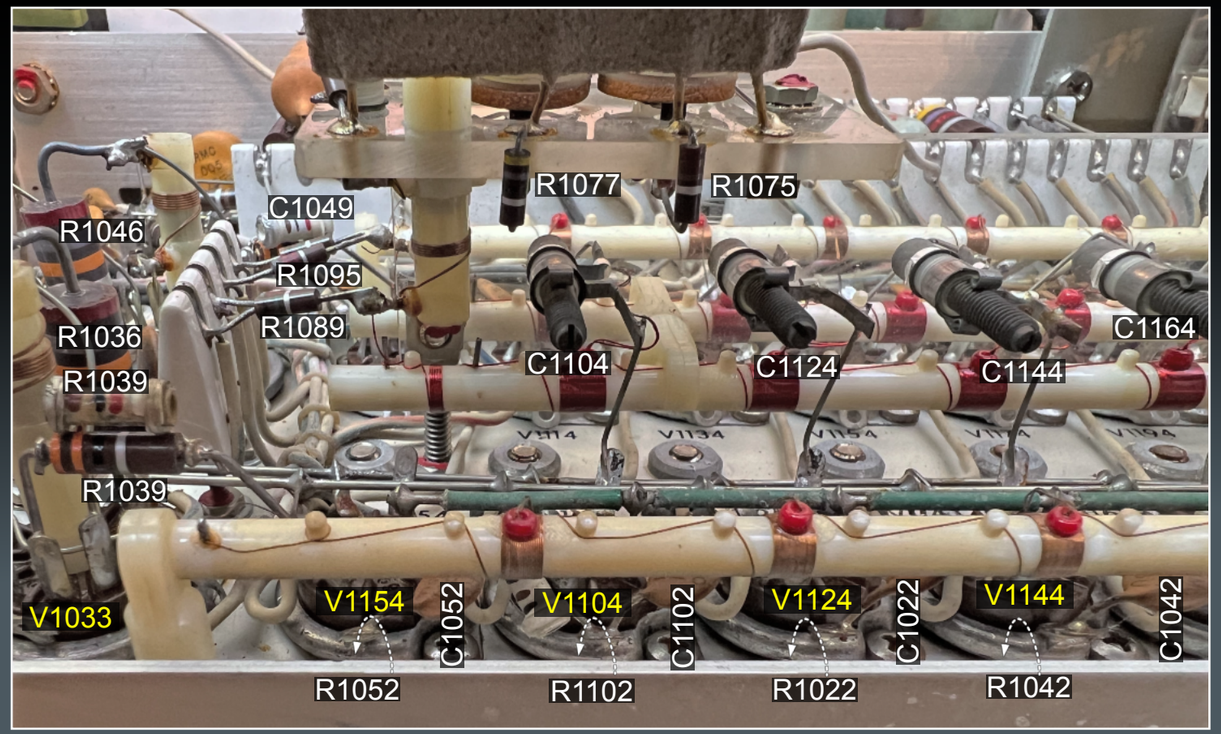
Vertical Amplifier



Vertical Amplifier

I was rather concerned for the Vertical Amplifier, because when I started the repair, it provoked a strange effect. The +100V voltage was at 148 V. After many tests sectioning the various chassis, I discovered that the culprit was the Vertical Amplifier. If I removed all the tubes, the voltage was normal. If I put two tubes (but maybe one was enough), the problem returned. I was stumbling in the dark, so I reserved to study this problem later and let the Vertical Amplifier disconnected.

After many other repairs, I decided it was time to afford it and reconnected the Vertical Amplifier. At my surprise, the problem was gone. I attribute this to one of the Bumblebees, C1007, which in the meantime I replaced (in the photo on the previous page has already been replaced with a modern one). All's well that ends well…





The Distributed Vertical Amplifier





500 Series

Subsection: High Voltage Circuits

Reading on the Internet, this is one of the most critical parts of this class of oscillo-scopes. My 545 was rather incomplete and messed-up, but I was lucky, finding on eBay a new HV Module in good state.

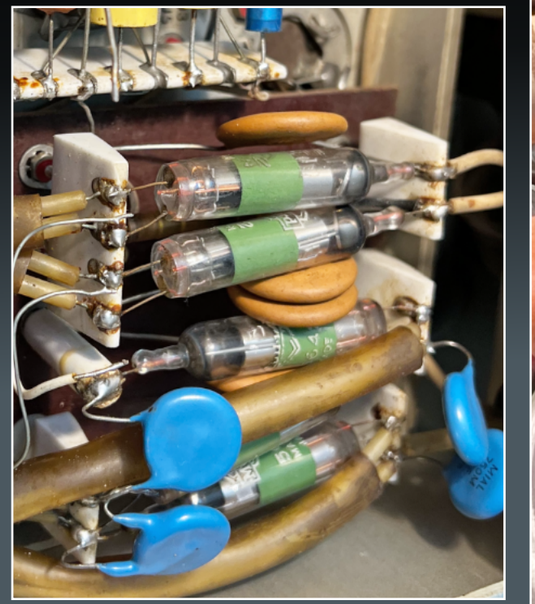
High Voltage Circuits

Any classic oscilloscope has a CRT inside, and any CRT needs high voltages to work. I had had few experiences in this area with the 7000 Series, the 561A, as described in my other books.

In this case, I had to go further, because my poor 545 had the HV section in bad conditions and partially disassembled; some unknown hands had messed it up. Thus, I decided to reconstruct the documentation for this section, hoping I could complete it with the missing parts and fix it.

Here in this page, you can see the “starting point”. Hard to imagine why they added that white additional winding, and which tube they wanted to use in place of the 6AU5GT with this strange adapter…





Producing High Voltages

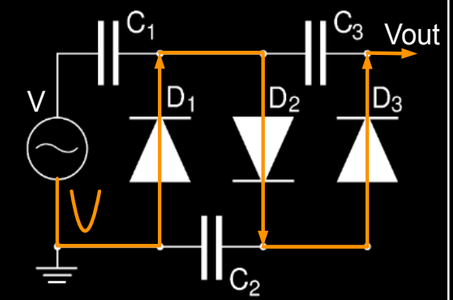
In the 545, the high voltages are generated by mean of a Hartley 60-kHz oscillator (V803), which converts the DC power supply in a high-frequency AC, so that it can be raised by mean of T803 ferrite transformer. A voltage tripler rectifier (see below), consisting of V821, V822, V823, C822 and C823 supplies about 8650 V for the post-deflection accelerating anode of the cathode-ray tube. The transformer, the rectifiers and some high-voltage capacitors are mounted on the HV module, painted in red in the schematic diagram here on the left.

I started my work carefully dismounting the HV module and taking notes of the connections. The manual does not give a name to them, so I added mine to make more easy to understand the connections. I reported also the colors of the wires. My pin numbers follow the resistance color codes (e.g. red = 2, yellow = 4, brown/yellow = 14 etc.).

Voltage multipliers

Voltage multipliers are as simple as fascinating. Their principle is very simple: in the negative half-wave all the diodes conduce, but D2 charges C2 on top of C1, D3 charges C3 on top of C2, and so on. Each diode adds a multiplication factor. In this case, we have a 3-time multiplier.

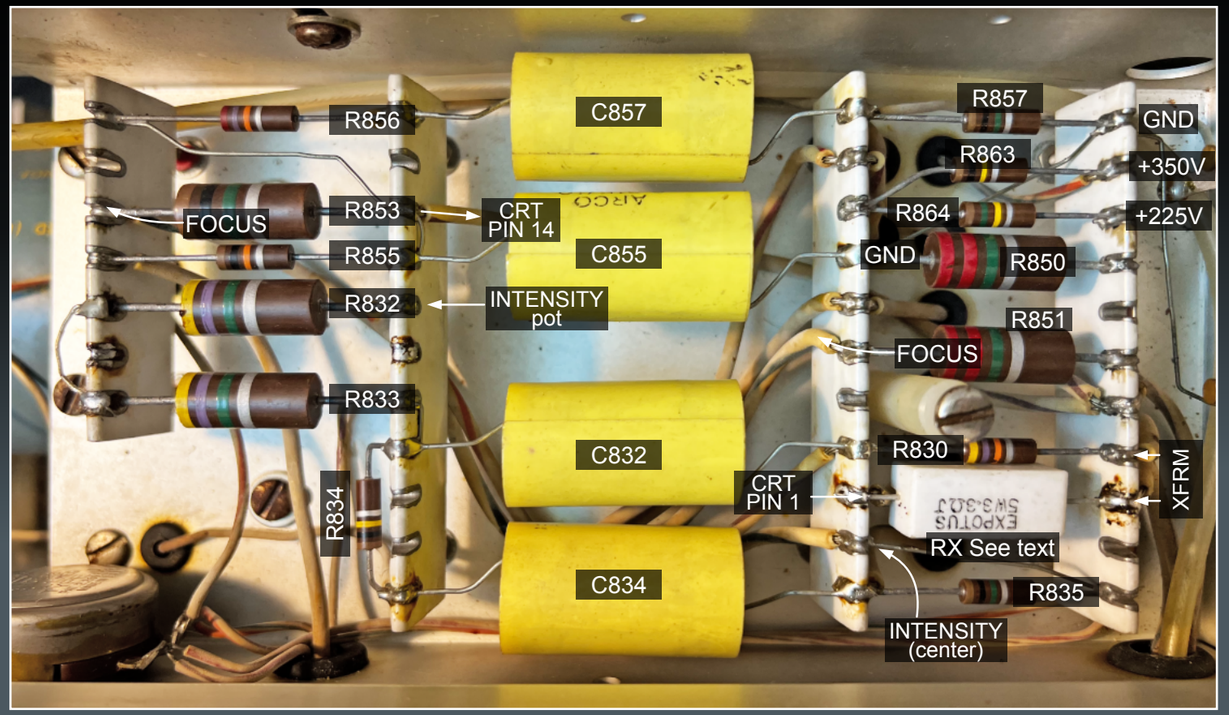
If you want to know more, on Wikipedia you can find all the details.

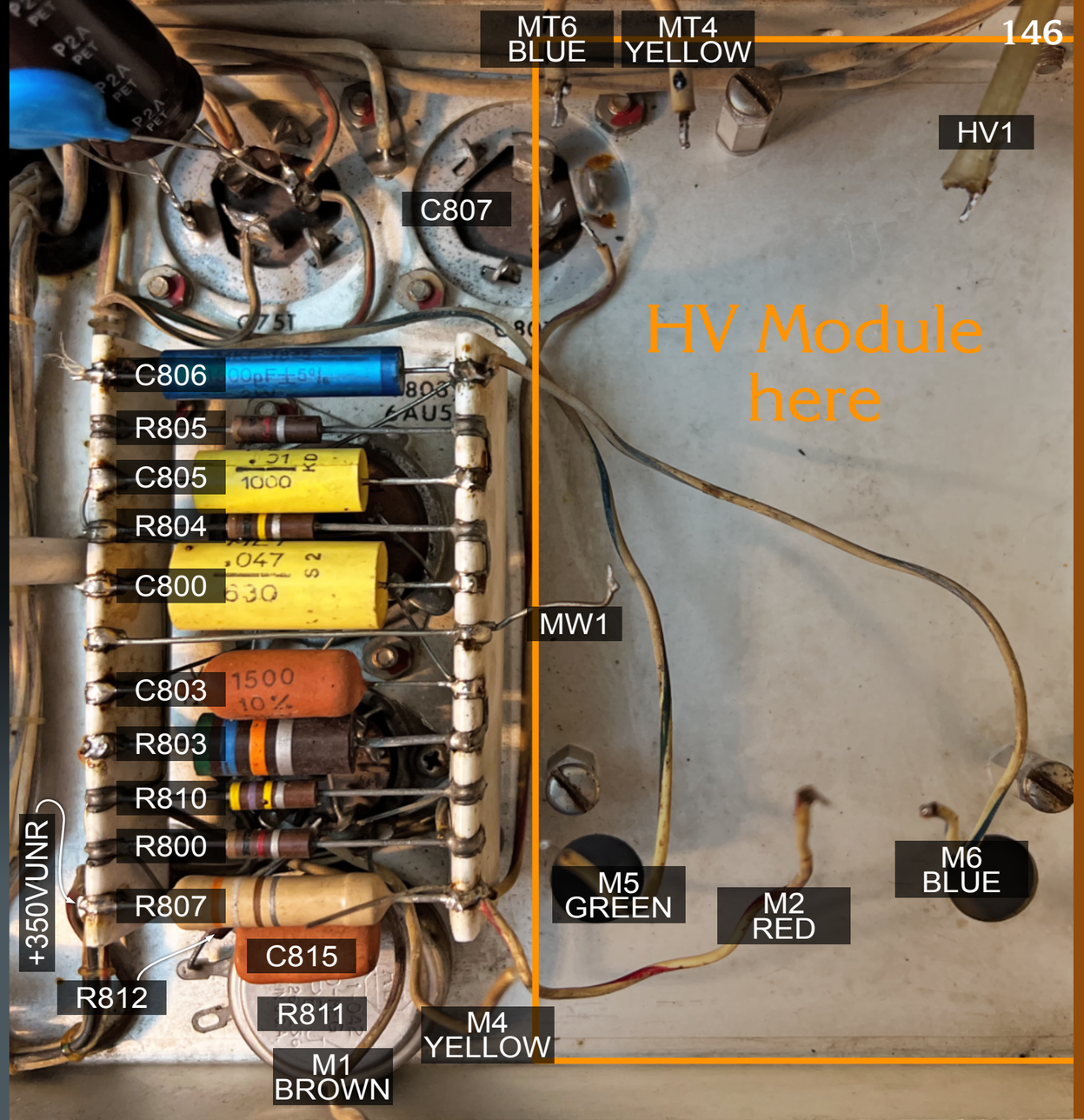


High Voltage Areas

Note RX in the photo below. It was not originally present but I found it already installed by the old owner of this instrument; it is just in series with the CRT's filament. I asked myself why they added it, and the only answer I could guess is that it is a way to reduce CRT wear off and risks. The CRT works well and is very bright, so I didn't try to remove it.

Wisely, the HV area is protected by some metal protection, but beware, however. As printed on these shields, the most armful voltages are 225, 350 and 500V, not the HT.





High Voltage Module

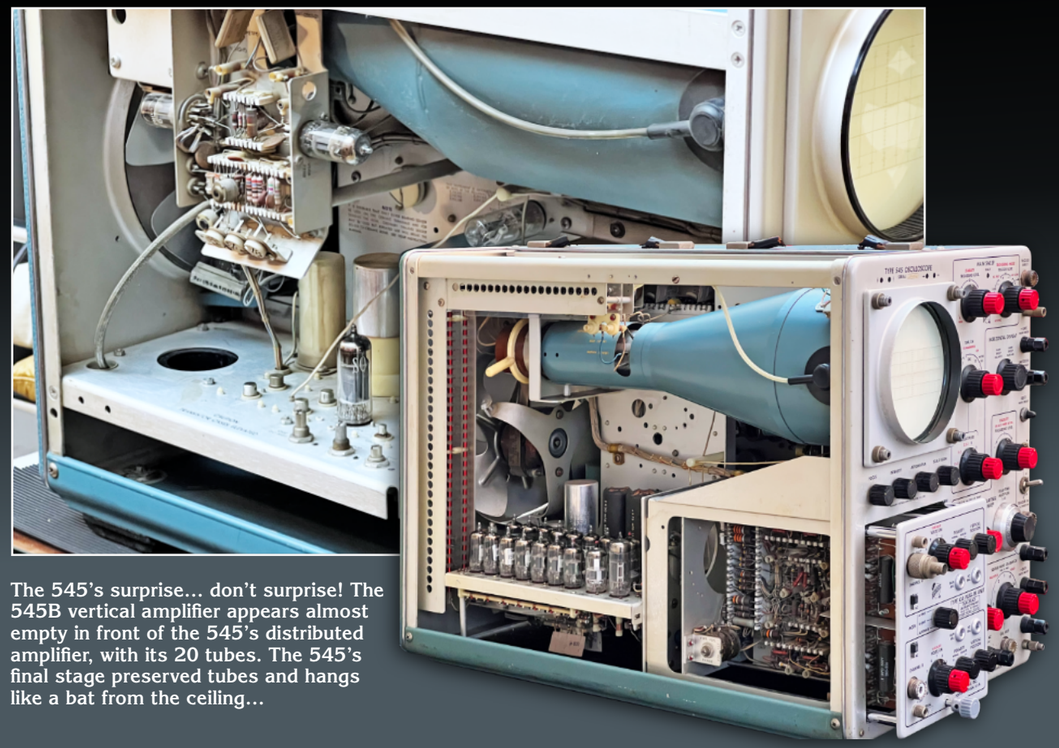


Bla bla bla

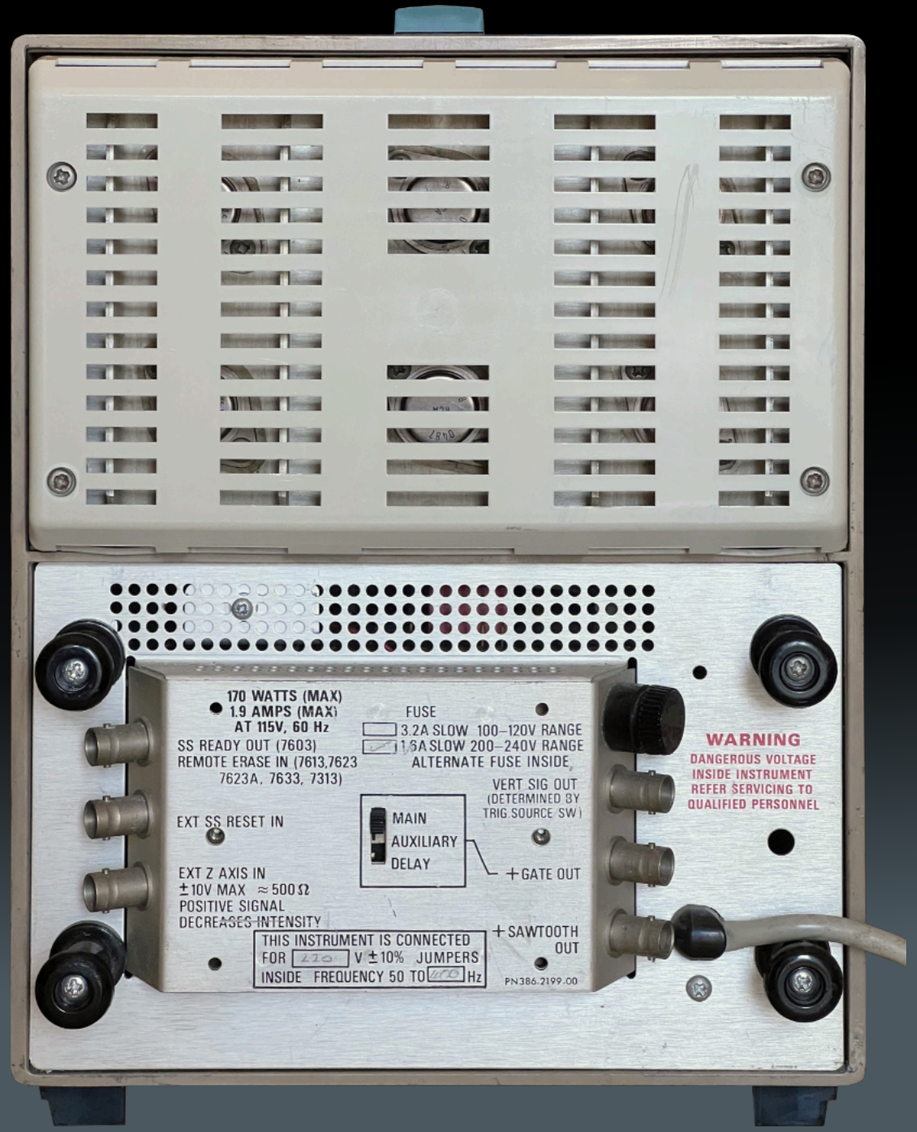
Its First Words

After a long coma and several surgeries, the 545 was not perfectly lucid after waking-up. He was surprised and glad to find himself together with so many other oscilloscopes. *Who won the cold war?* asked me. *What about the Cuba rockets? Are we safe here against a possible attack from the Soviet Union?*

He was also surprised seeing that its younger mate, the 545B, had inside something capable to amplify signals without having a warming filament, and despised, but envied, its new vertical amplifier without a double dense tier of tubes. And, until now, I didn't tell it about integrated circuits and software…



The 545's surprise… don't surprise! The 545B vertical amplifier appears almost empty in front of the 545's distributed amplifier, with its 20 tubes. The 545's final stage preserved tubes and hangs like a bat from the ceiling…



7000 Series

7xx3 Linear PSUs

Power Supply Units are the most critical over the time, Here we analyze rather deeply the linear type used in 7000-Series models with a final “3” (7403, 7603, 7623, 7633 etc.), describing its circuit and giving suggestions for its repair.

Repair linear PSUs

The weak link

Since the invention of electronic devices, the power supply section is the weak link in the chain. Maybe because it is one of the more stressed parts, maybe because it uses electrolytic capacitors, less stable over the time respect to other components.

Here we report some notes about repairing the linear (i.e., non-inverter-based) Power Supply Unit (PSU), used in the 7000-Series smaller models (which end in "3", like 7403, 7633, 7623A etc.). All the references are however related to the 7603, but the differences with the other models are minimal and are however partly analyzed. Another chapter of this book is related instead to the Tektronix High Efficiency Power supply (HEPS), used in the bigger models, whose name ends in "4".

Documentation

Tektronix manual 070-1429 is well done and its explanations are rather clear. On TekWiki, you can also find a redrawn electric diagram, easier to read that the original one in the manual.

Removing the transformer assembly

To remove the transformer assembly, you have only to remove four screws, but you must be very careful extracting it because there are many cables that connect to various parts of the equipment and furthermore some cables pass through it to reach the rear panel A12 signal outputs board, linked to the BNC connectors. Those cables do not interact with the power supply, and if you are going to service the PSU, you can disconnect and forget them. If you like as I do to work comfortably, you will extract the PSU completely. To do that, you have to remove also the connections from the power switch.

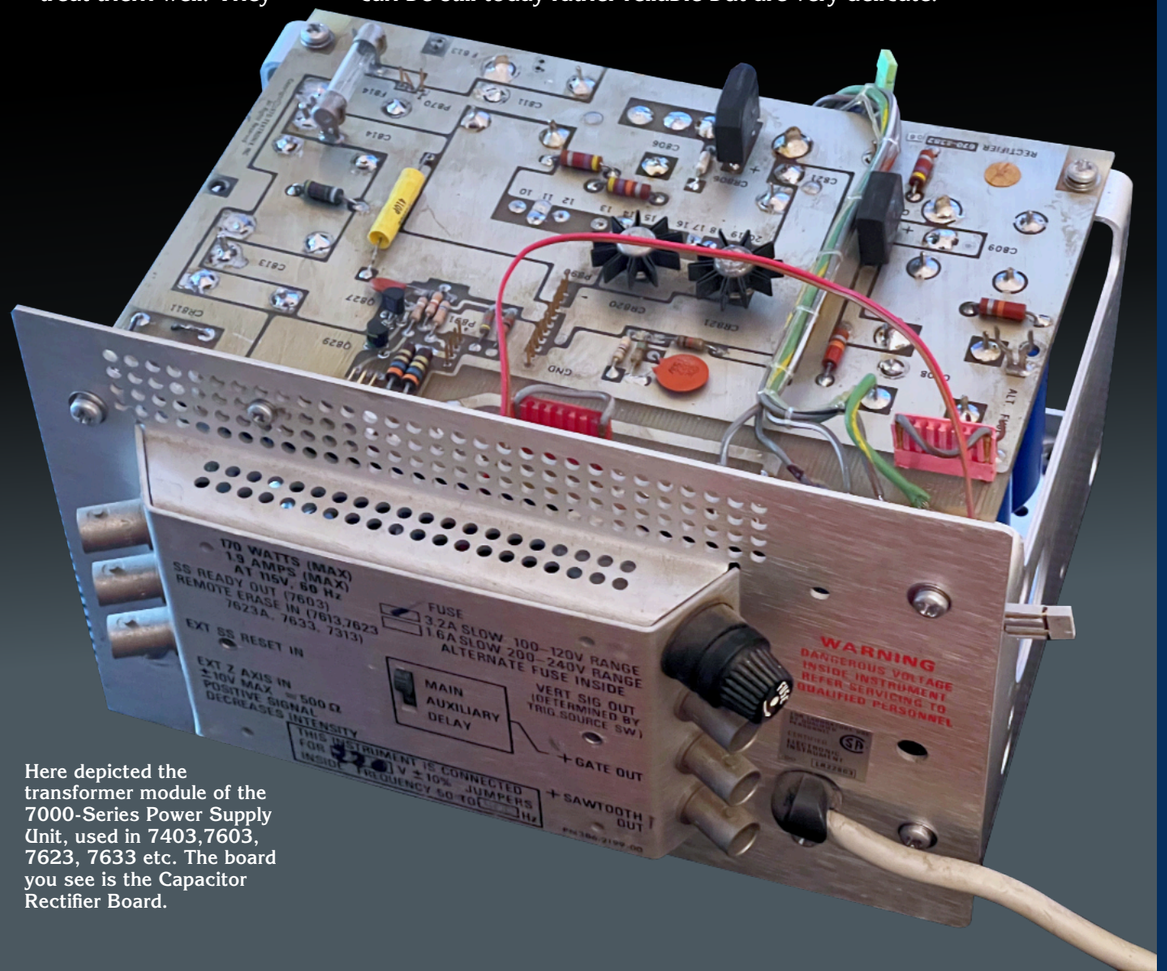
Caution

I recommend you something that seems completely obvious, but it could come the time when you forget that, so be very, very careful:

- **connectors**: flat cables were novelties at that time and had connectors not yet polarized/driven. That means that you can mount the connector in 1) the right way; 2) 180°-turned; 3) shifted by

one or more places on the left or on the right. All the solutions but 1 are catastrophic. You will say: it is obvious, I am not so stupid, it cannot happen to me. Good for you, but before turning on the power check all them again, you could get surprises…

- **photos**: when you dismount, it seems easy to remember where the connectors were mounted. When you will go to remount them, you realize you forgot everything. So: take photos of every connector you detach. The general wiring schematic (see page 161) can be a help, however.
- **sockets**; all the transistors and the ICs are mounted on almost invisible sockets. Be careful and treat them well. They can be still today rather reliable but are very delicate.



Here depicted the transformer module of the 7000-Series Power Supply Unit, used in 7403,7603, 7623, 7633 etc. The board you see is the Capacitor Rectifier Board.

The Circuit

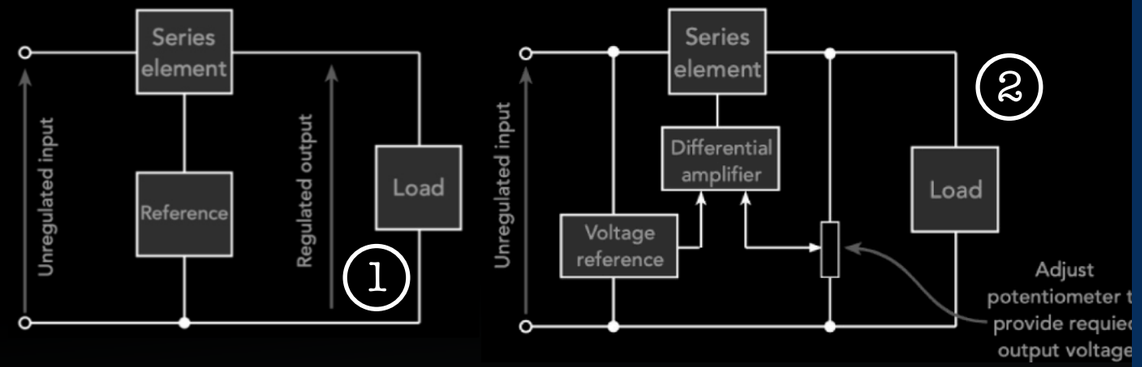
In 1969, when energy was not a concern, inverter-based power supply was a luxury novelty reserved to the 7704. The 7403, 7603's progenitor, used a more conventional approach with a fully-linear power supply, where the excess energy was simply dissipated. These power supply sections are composed by two modules. For example, in the 7603, by the A10 Rectifier Board, mounted on the transformer assembly, and the A11 Low Voltage Board. Both of them are rather conventional, but the circuit is complicated by the necessity to create 6 voltages: +50V, -50V, +15V, -15V, +5V, +130V. Looking at the schematic diagram, each section seems to be dependent on the others, but many connections are only for protection. However, each voltage is in some way related to the –50V, so that to have just one trimmer for all.

Sense feedback

Like any stabilized power supply, this circuit operates as a closed loop, to adjust the output voltage as a function of the load changes, but here we have a difference: instead of reading the voltage at the output of the regulator circuit, we have a separated wire to read it at destination, compensating the voltage drop on the main supply wire. I report the figure from the manual that explains this concept. Note however that this kind of approach is used only toward the main interface board, perhaps to compensate the differences in the plug-in loading, whilst the largest part of the internal circuits doesn't use this feature.

Basic operation

In diagram you can see the basic series regulator circuit. The input voltage is always higher than the desired output and the current toward the load is the same in input as in output. But, as you know, the power is given by the product of the voltage times the current. For example, we could have: Vin = 15V, Vout = 5V, I = 1A. We have 15W (15 x 1) in input and 5W in output (5 x 1). And where did they go the 10W difference? Simple: it goes in heat, normally dissipated by the Series element. For this reasons, power supplies circuits like the 7000-Series are today rarely used, preferring switching regulators, which operate on a completely different principle, much better from the energy point of view, but which could also produce unwanted electrical noise, not welcome on an instrument like this, but, above all, more complex to realize without integrated circuits.



❶ The basic regulator circuit maintains the reference voltage at its output.
❷ The closed-loop regulator circuit takes in account the effective voltage on the load.
❸ Some oscilloscopes using the linear PSU. From the left: OS-254(P)/U, 7603, 7603, 7603N, 7623A.



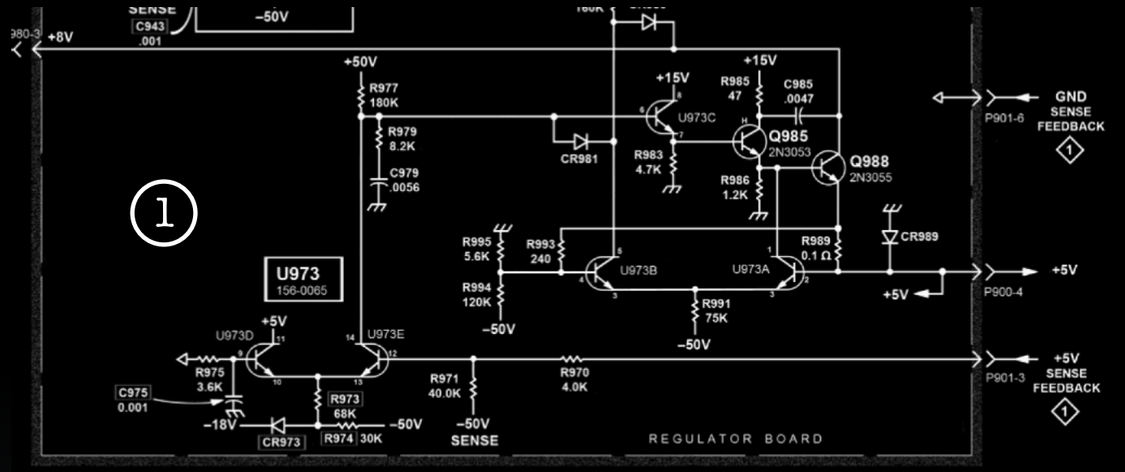
Circuit description

Coming back to our case, the 7000-PSU follows the scheme depicted in . The adjustment potentiometer is present only on –50V, the other voltages are in someway linked to it, as we noted before. We will see now, how this scheme is realized in the 7603 PSU. We will analyze the +5V section, that is rather simple (following figure).

- **Voltage reference and differential amplifier.** this subsection has:
  - as input: the SENSE FEEDBACK line from the +5V rectifier/filter board
  - as output: the voltage reference, collector of U973E (pin 14).

U973D and U973E compose a very simple differential amplifier that decides the output voltage. The left branch read the reference voltage, 0V thru R975, while the right transistor is connected to the sense feedback of the stabilized +5V. If you calculate the voltage divider composed by R970 and R971, you can see that base of U973E stays at 5V. In fact, 55V x 40,000 / (4,000+40,000) = 50, relative to –50V, so practically 0V. Thus, the output of the differential amplifier (collector of U973E) is at +5V when the other voltages are at their nominal value.

- **Series element.** The series element is Q988, but it cannot be driven directly by the output of the differential amplifier, so U973C and Q985 are required to amplify the required current. U973C, Q985 and Q988 constitute thus an amplifying chain of cathode followers. Each of them has a voltage gain of 1, but amplifies the current. The small resistance on the Q985 collector has probably only the purpose to limit the current. The final transistor Q988 has not an emitter resistor, like the others, because its load are… the oscilloscope circuits it feeds!
- **Regulation**. If the load sinks more current, the +5V SENSE CURRENT decreases, and so U973E conduce less, increasing the voltage at its collector and thus at the base of U973C, and, in consequence, at the base of Q985 and Q988, and thus to the load. Similarly, and opposite when the load decreases. Note that the regulation is performed also when the supply voltage changes.
- **Overload protection**. The circuit is protected in the case of an overload on the output. This task is performed by adding a very small resistor in series to the load (0.1ohm, in this case), that do not alter the main current flow but that allows to measure the voltage drop across its terminals, and understand if an excessive current is flowing. We find here again the same comparator circuit that we saw for the voltage reference, composed by U973B and U973A. The two input to the comparator are the transistor bases, that are placed across the 0.1ohm R989 resistor. When the difference between them exceeds a certain value, U973C starts conducing and set negative the base of Q988,



❶ Partial LV Board schematic, the +5V section.

limiting the current.

+130V supply

The circuit for this voltage is different. There is not a transformer secondary for this voltage. The transformer delivers about 80V. They are “summed” with +50V by mean of Q850 and regulated by Q852. Furthermore, there is no current protection circuit but just a fuse (F855).

Current measurement

The resistors designed to be part of the overload protection can also be used as a simple mean to measure the current of each voltage. Just measure the voltage across them. For +50 and -50, the read value is the current value. For +15, -15 and +5V, you must divide the read value by ten (e.g., if you read 1V, the current is 100mA).

The picture helps you in that: you can see the resistors where measure the current and the points where measure the voltages. For the currents, it is reported if you have to divide the read value.

Testing

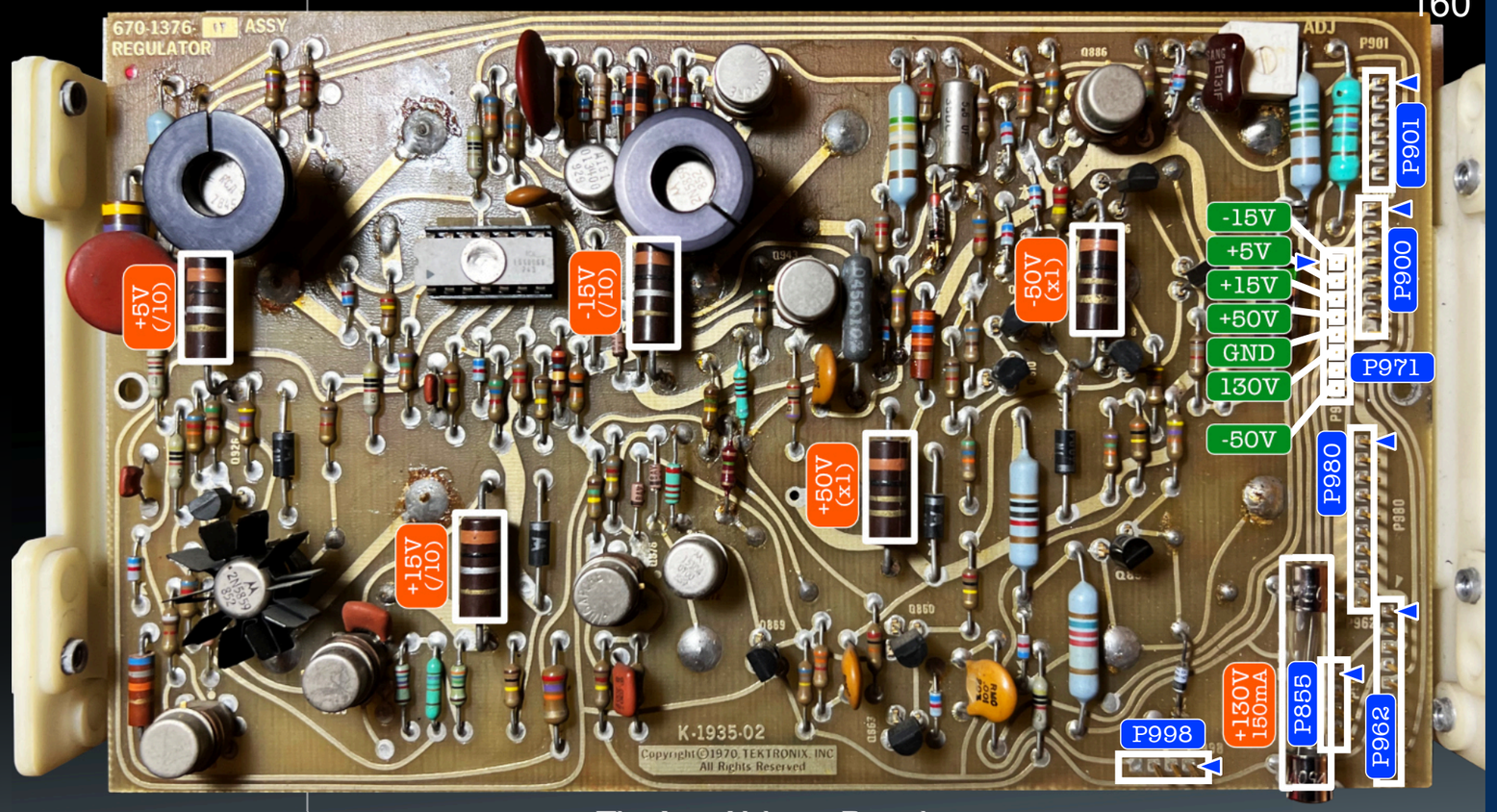
First power-on approach

In the case of an old scope that you try to power-up for the first time, remember always to check in advance the resistance values at the various voltages delivery points; you can find the correct values in the oscilloscope's manual. If the fuse repeatedly fails, the best is to use a variable transformer (VARIAC) to gradually increase the supply voltage, so that you can better debug the circuit. In addition, some tips follow.

- **Line voltage.** Check the line voltage. Some scopes travelled from the States to Europe, so don't assume that the setting is correct for your country.
- **Fuses.** Check the fuses. If they are blown, a different approach is required.
- **Plug-ins.** Remove all the plug-ins from the scope.
- **Disconnect secondary circuits.** It is useless to stress also the circuits that are not immediately useful. Disconnect from LV board the following connectors: P971, P998, P981 and P962.
- **Disconnect the High Voltage Board.** It is better to have not to deal with the possible HV problems. Detach P1130 from the A8 Z-Axis amplifier board. Explanation: the A9 High Voltage board, that generates the 7.5kV voltage for the CRT, is powered by the +15V UNREG. This line starts directly from the A10 rectifier board (transformer assembly), thru the A8 Z-Axis board. The +15V UNREG is passed as follows:
  - A10 rectifier board, P870 A8 Z-Axis board, P1130;
  - A8 Z-Axis board, P1120; A9 HV board, P1220.

Checking the outputs

A good point to measure voltages in on the horizontal amplifier (see a picture at the end of this chapter). Connect the VOM between -50V and ground and briefly switch on the equipment. Operate in a quiet room and listen carefully for any sound, that can help you to detect a possible problem. If nothing exploded or smoked, you are a step forward. If the voltage is OK or almost OK, you are two steps forward and can continue checking the other voltages.



The Low Voltage Board

Dummy load

If you are going to work on the PSU alone, you should better build a dummy load, because without it the PSU does not work, i.e., it requires a certain load to operate. Don't forget to connect also the sense lines. I read that without it we can produce some damages, because the PSU will increase its output current as much as it can. It is advisable also to place an electrolytic capacitor on the dummy load inputs.

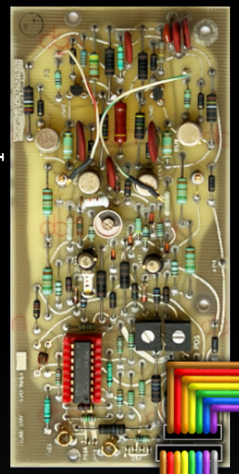
Mainframe Wiring

It is not easy to understand 7603's cables and connectors that go almost everywhere. In the "7000 Series" book, you can find many drawings and schematics which can help you considerably; I report one of them here. In general, you have a connection to the main interface board, and from it a branch to the amplifiers (H, V and Z) and a branch to the calibrator and the readout board.





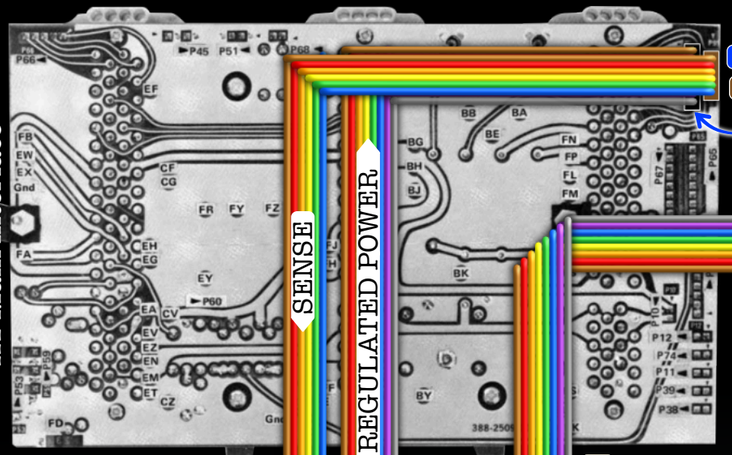
A13 Readout



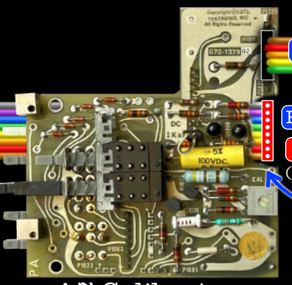
A6 Horizontal Amplifier



A5 Vertical amplifier



A1 Main interface



A7 Calibrator



A12 Signal output



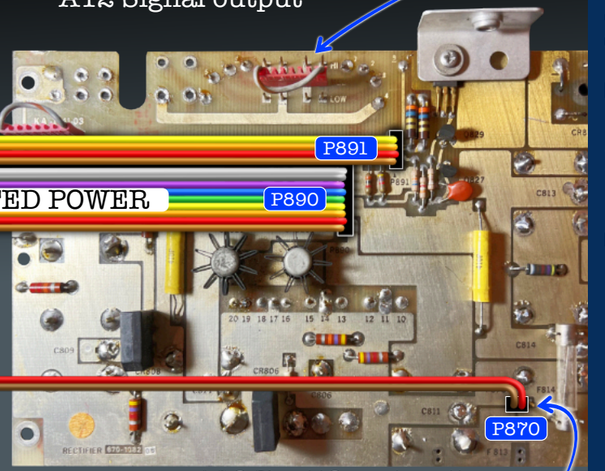
A9 High-voltage



A8 Z-axis amplifier



A11 Low-voltage regulator



A10 Rectifier circuit

P91
brown
P90
8
5
P1071
To P2171
Readout bo
P1092
red
(On back side)
SENSE
REGULATED POWER
5
P901
brown
P900
8
P962
red
8
WARNING!
Two pins
remain free
2
P678
P980
P971
brown
P955
P998
7
P901
P2171
5
To P1071
Calibrator board
Line voltage
RED=230V
BROWN=115V
4
P891
UNREGULATED POWER
P890
8
P1170
P1171
brown
8
10
8
P1130
2
P1120
+15V to power
the HV board
thru Z-axis bd.
P870
WARNING!
One pin
remains fr

Repairing 7xx3 Linear Power Supply Units

Problem Fixing

Wrong voltages, what can I do?

If one or more voltages are wrong, I suggest you stop and remove the transformer module. It is highly probable that one or more electrolytic filter capacitors are no longer good. As we said, it is rather simple. See “Removing transformer assembly”. When dismounted, place it on your workbench and start checking it. Don’t worry if the voltages are higher than reported by the schematic. It is normal, being them unregulated and without the load.

If you have a capacimeter, use it to verify the capacity of the big electrolytic capacitors. It should be about the nominal one or bigger. If you have not the capacimeter, you can check the voltage on the filter with the oscilloscope. If it is pulsating instead of pure DC, you need to replace the related capacitor. Follow the schematic, it’s rather easy.

If the capacitors are good, the problem is likely in the LV Board (see below).

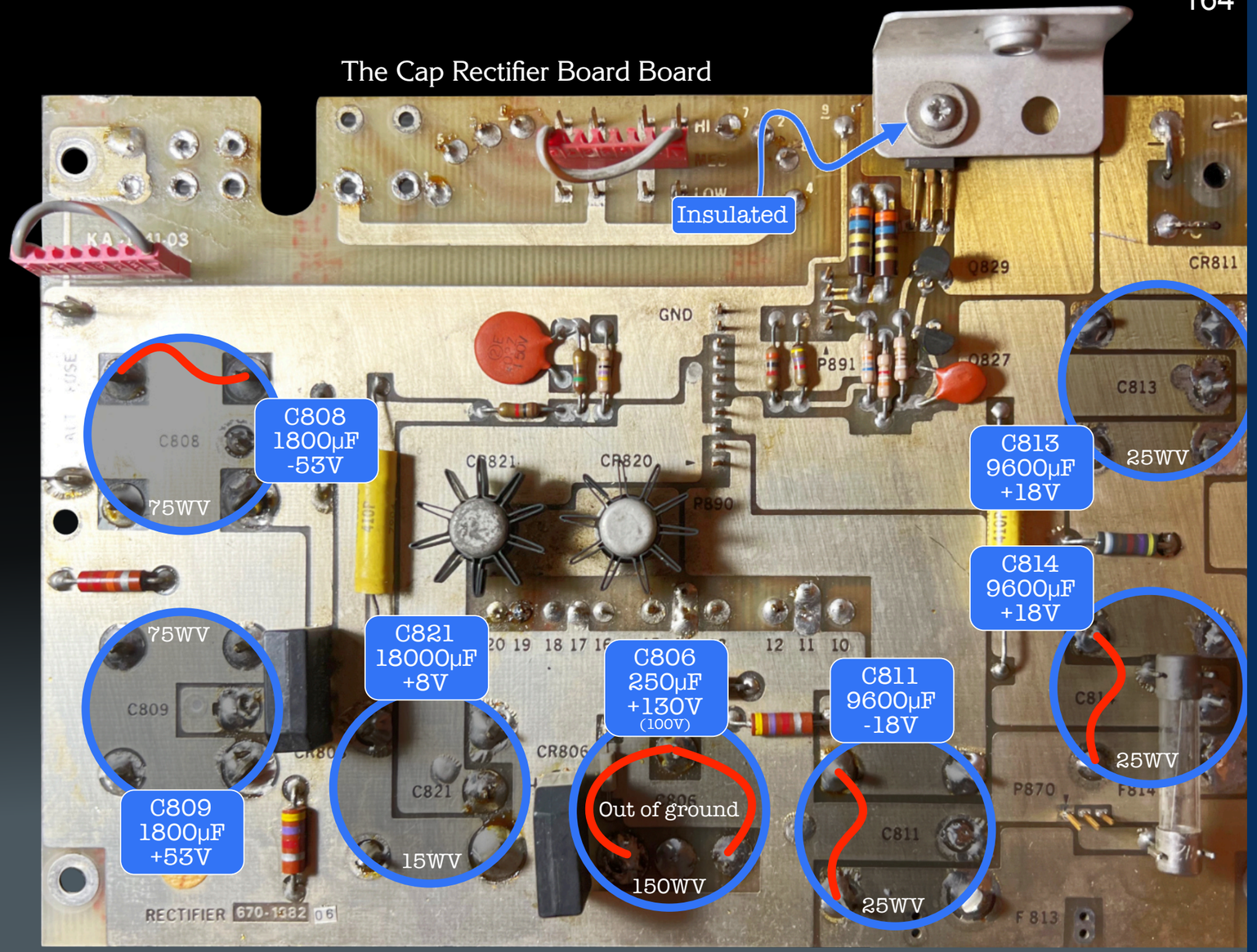
Repairing the Rectifier Board

The most common fault is the aging of filter electrolytic capacitors. If one or more voltages are wrong. If you have a suitable VOM, you can measure them; the value should about the nominal. The best test is however with an oscilloscope. If there is a pulsating voltage where you expect a pure DC, the problem is evident and the capacitors must be replaced.

“Recapping”

Replacing the capacitors (“recapping”) is something that I hate: a brutal work on a delicate electronic stuff. I never succeeded unsoldering those old capacitors; they are big and heavy, and, even with a big solder, it’s likely you will damage the PCB. I found that the best way is sawing them away. You can use a hand saw, like in the

The Cap Rectifier Board Board



picture on the previous page, or a common “multifunction tool” (I don’t know how to call it, it is a motor that makes a blade saw to oscillate at high speed; mine is from Makita). It is rather difficult, when not impossible, to remove just one capacitor in this way; the recapping is then always for two or more (it depends on their position).

When you carefully have cut away the capacitors, you must cleanup the PCB from the tin, and that also could make you suffer to avoid damaging the PCB itself. I use a 100W gun solder with a small tin pump, but something bigger would be required to do a good work.

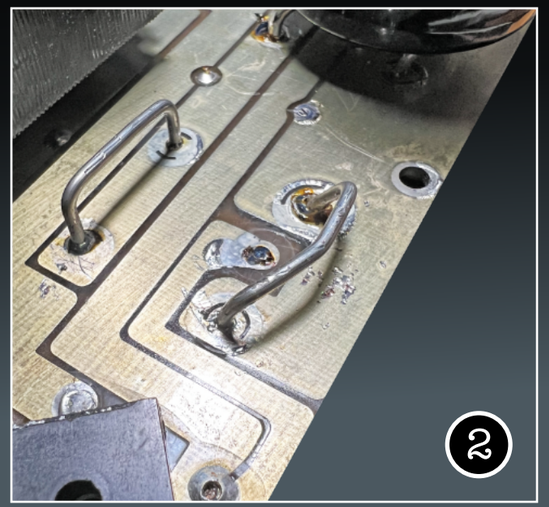
Today capacitors are much smaller and you could want to increase their capacity. Personally, I am rather prudent about modifications, so I normally remain on the original values.

Recapping tips

The picture here on the right on next page can help you in the recapping process. I suggest the following tips:

- remember that some capacitors’ metal cans are used to ensure the ground continuity, i.e. as jumpers. Today’s capacitors have only two pins, so you need to add wires where required. The picture shows you in red the jumpers I added, but that depends also on where/how you connect the capacitors;
- the “INSULATED” label says you that the square bracket used as heatsink must be insulated by using the special dedicated plastic washer. If you omit it, you will produce a straight short on the +8V, risking to burn the transformer;
- the +130V voltage is really much lower, because it is added with the +50. Without any load, I can measure there about 100V;
- the above said +130 is not referenced to ground, so you must not be scared when you read zero. Measure it between the two capacitor’s poles;
- C811 is 1800 uF in 7403 and 2400uF in 7603.

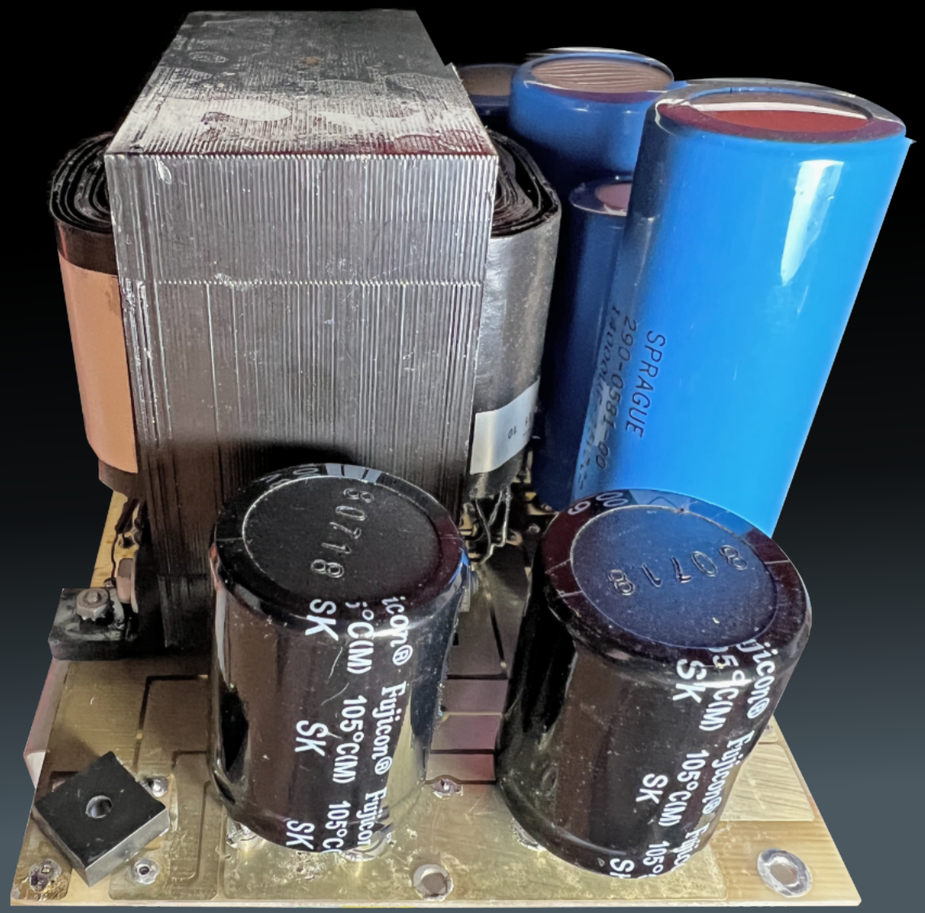
At the end of the soldering work, clean the PCB with a specific product.



❶ The terrible operation of removing the old capacitors.
❷ The re-created connections are needed to save the connections ensured by the capacitors’ cans.

Repairing the LV board

The LV Board is more complicated, but not as much as it seems. When repairing it, we have however powerful allies: the sockets. What I am suggesting you is the inglorious repairer's way: just check every transistor with the VOM, without puzzling too much. It seems slow but could be time saving instead.



Partial recap. Two smaller capacitor replace the old ones. It is probably convenient not to stop here and complete the replacement.

If you prefer the true man way, you can remount the transformer and try to debug the circuit in the classic way. I am rather lazy and prefer the coward approach of checking first every semiconductor. By the way: I have found also faults caused by open resistors, not only by transistors. Testing the transistors with the VOM is very easy, search on the net, you will find lot of videos and tutorials.

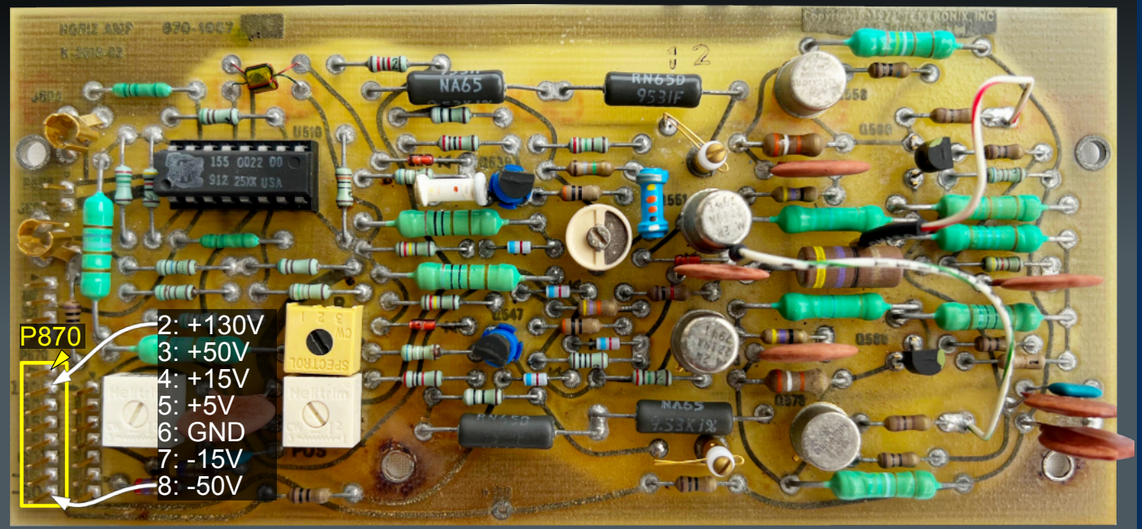
Note also that there are two kind of possible problems:

- the LV board is faulty and is not able to supply the correct voltage. You can only fix it.
- the LV board is OK, but the load is excessive. This should not be the case, because we already checked the mainframe lines resistance, but that test is not exhaustive, because some component could go into short only above a certain voltage. In this case, it's useful to perform the current measurement that we discussed before. Check the voltage across the overload resistors. I have no limit value to give you, but it is rather easy to see if a voltage is in the overloaded state. In that case, you have to find out elsewhere the bad guy and not to repair the LV.

A good point to measure voltages in on the horizontal amplifier. The picture below shows you where to put the probe.

As final tuning, don't forget to adjust R881 on the LV board to set -50V at its exact value. All the other voltages should stay in their nominal value ±0,1V.

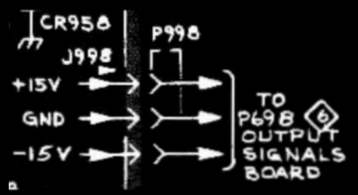
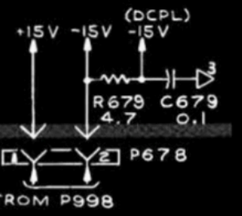
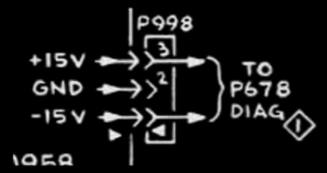
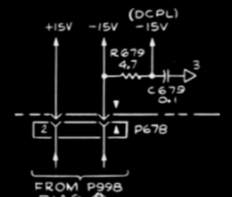
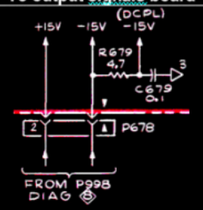
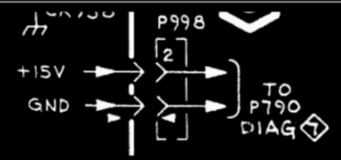
Voltage test points on the horizontal amplifier board.



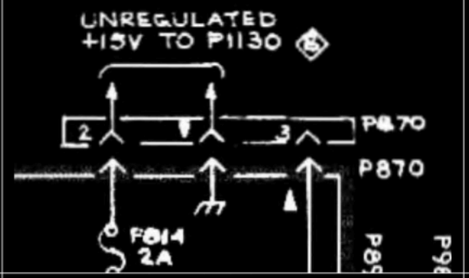
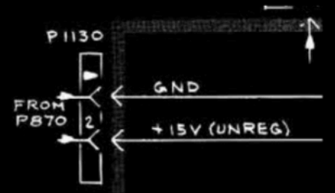
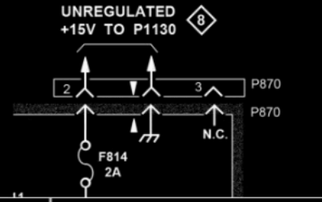
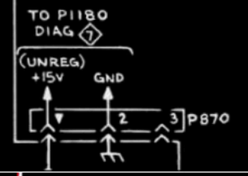
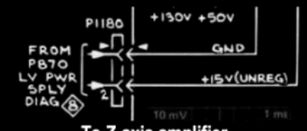
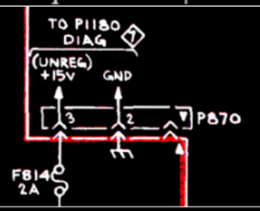
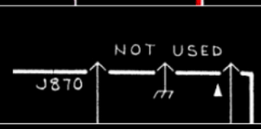
Special notes

Pay attention that P870/P1130 are a little tricky (see the table below with the connector schematics):

- P870 has 3 pins, whilst P1130 has two; the cable has 2 wires;
- the schematic in the 7603 manual could be rather confusing, because pin 1 of the cable has been drawn on the pin 2 on the PCB;
- the file “Tek_7603_power_supply_A10_and_A11_schematic_(redrawn)” that you can download from TekWiki contains an error on pin 1 of P870 marking;

	From P998 on LV board	To
7603		 To output signals board
7623A		 To output signals board
7633		 To output signals board
OS-245(P)/U		 To Z-axis amplifier

I report also the 7623A and 7633 schematics that are clearer. Substantially, you have to connect P1130 pin 1 to GND and P1130 pin 2 to +15V. In the OS-245(P)/U (the so said military version of 7603, that is really a 7403), the output signals board is not present and the HV Board is powered by the regulated +15V, taken from P998 on the LV board.

	From P870 on rectifier board	To
7603		 To Z-axis amplifier
7603		← Wrong pin 1 indication in the file Tek_7603_power_supply_A10_and_A11_schematic_(redrawn)
7623A		 To Z-axis amplifier
7633		 To Z-axis amplifier
OS-245(P)/U		Not used



The dual beam masterpiece 7844 CRT: two CRTs inside the same enclosure.

All Models

High Voltages and CRT circuits

CRTs require high potentials to perform their operation. In this section, we shortly explain how a CRT works and how signals from other circuits are translated in level to control the CRT. Some suggestions on how to deal with high voltages are in addition supplied.

Repairing CRT Circuits

Differently from today's equipment, in which the display is just a secondary component that we can easily change as we like, sometimes also in real time, the focal component of our beloved oscilloscopes is the Cathode Ray Tube (CRT), and I find very interesting its inner operation.

If you also like to understand how does it work, I suggest reading the Tektronix book "Cathode-ray tubes" by Chuck DeVere and Bob Orwiler that you can download from TekWiki (http://TekWiki 3https://w140.com/tekwiki/wiki/Concepts_Series).

Required CRT electrodes potentials

From that book we can learn a lot, but for what we are going to see now, the diagram ❶ is the most important. It tells us that:

- the cathode is the reference potential;
- the grid must be kept somewhat more negative;
- the anode must stay much more positive.

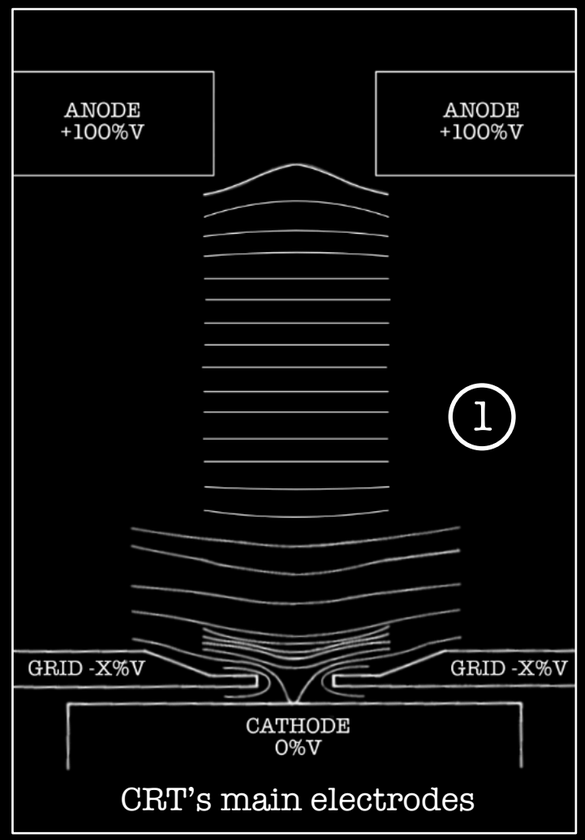
In an oscilloscope like the 7844 that we will take as a case study, the cathode is held at 2,960 V (nominal), so the grid will stay some tenth volts below. But how to connect to it the Z-axis amplifier, that has an output of about 0-65V, without bursting that all?

The inverter

All the high voltages (and also low voltages in 7904, 7834, 7844, 7954 etc.) are generated by mean of an inverter, i.e. a DC powered oscillator at about 25 kHz, which drives a transformer. On one of the secondary windings of this transformer, a square wave of about 1,5 kVpp is present.

Translating DC voltages by mean of AC

The principle that stays behind the voltage translations is very simple: instead of translating DC voltages, we generate new DC voltages starting from the same HV AC (square wave from the transformer).



CRT's main electrodes

The clamper

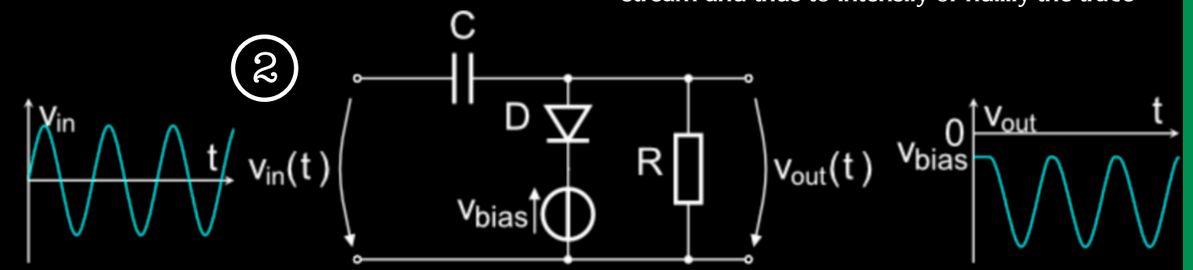
This translation is performed using, among others, a clamper, an electronic circuit that…

> …that fixes either the positive or the negative peak excursions of a signal to a defined voltage by adding a variable positive or negative DC voltage to it. The clamper does not restrict the peak-to-peak excursion of the signal (clipping); it moves the whole signal up or down so as to place its peaks at the reference level (from Wikipedia).

The clamper circuit is extremely simple, and requires just one diode and one capacitor: in figure ❷ you can see the negative version of it. The output voltage is Vout-pp = 2 × Vin-pp + Vbias, so the clamper is also a voltage doubler.

A real case

Let's look now at the 7844 schematic diagram (pages forward); It is not so different respect to other Tektronix scopes, and let's consider the way in which the Z-axis amplifier is connected to the CRT control grid (like in a normal tube, the control grid allows to open or close the electrons' stream and thus to intensify or nullify the trace



The clamper

brightness on the screen). As we said, a direct connection is not possible. The solution is very simple: we use the clamper, with the cathode voltage as bias.

Coupling the Z-axis to the clamper

You could think that the Z-axis amplifier signal is used directly as V(in) to the clamper, but it is not so. The input to the clamper is again a 25 kHz square wave (from the same transformer) with the amplitude controlled by the Z-axis signal. In reality, the amplitude of this square wave is controlled also by the setting of the GRID BIAS trimmer.

The clipper

That all happens with the help of a circuit called clipper, very similar to the clamper but with the capacitor replaced by a resistor and a different effect; paraphrasing Wikipedia, we could say:

> The clipper restrict the peak-to-peak excursion of the signal; it does not move the whole signal up or down as the clamper do.

The DC restorer

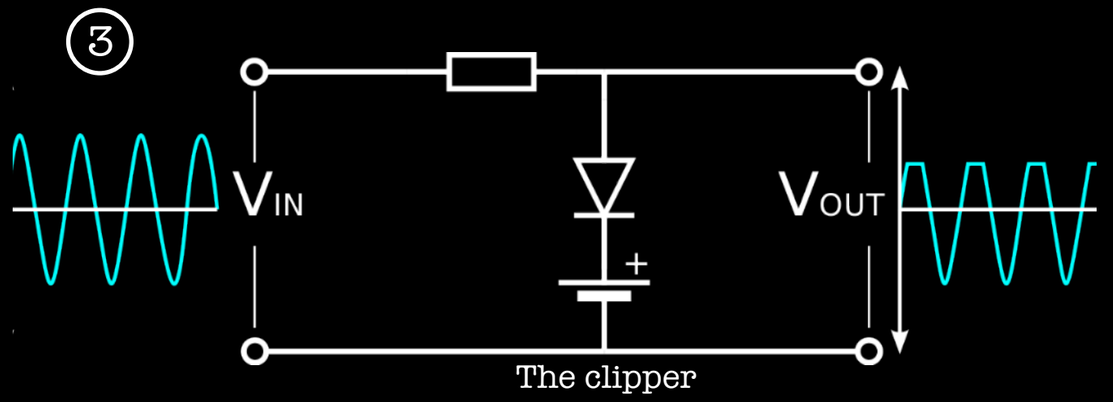
We have here (see ❹) two clippers that work together, restricting the amplitude of the square wave:

- the top clipper (diode CR2322 in the schematic) clips the top of the square wave to the voltage set by the GRID BIAS trimmer;
- the bottom clipper (diode CR2323) clips the bottom of the square wave to the output voltage of the Z-axis amplifier.

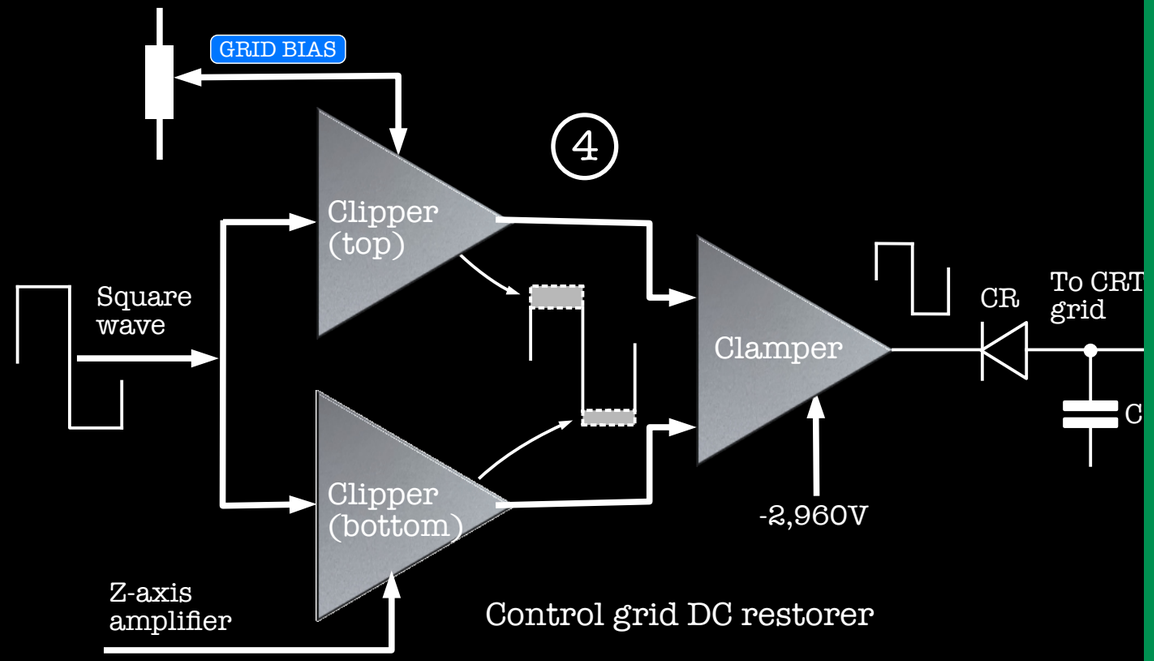
This clipped square wave can be routed to the clamper that, as we already saw, add the -2,960 V bias. But the output of the clamper is again a square wave, so a diode CR (CR2324) and a capacitor C (C2323) must be added to rectify it before eventually reach the grid.

In a short, we could say that the effect of the Z-axis amplifier and the GRID BIAS trimmer is to supply to the two clippers the correct bias, and that the two clippers together produce the signal to be "biased" before reaching the grid.

All that above is called DC restorer.



The clipper



Control grid DC restorer

Putting Things Together

Now that we have the bricks (the DC restorers) we can try to understand the whole wall. With reference to the ❶ diagram on the right, you can see that:

- both the DC restorers have a fixed point input (GRID BIAS and FOCUS control). The focus DC restorer is very similar to the control grid one, see ❷);
- the INTENSITY control works indirectly thru the logic board that commands the Z-axis amplifier to produce a dark trace with a zero voltage or a certain level of brightness (65 V is the maximum). During the retrace time, obviously the level is always zero, so the signal is normally a rectangular wave light/dark. To be clearer, the INTENSITY control does not go directly to the CRT circuit but the intensity information is embedded in the Z-axis amplifier signal;
- the INTENSITY control if fed however to the autofocus amplifier, that must match the focus with the current intensity setting. Some trimmers allow the proper adjustment.

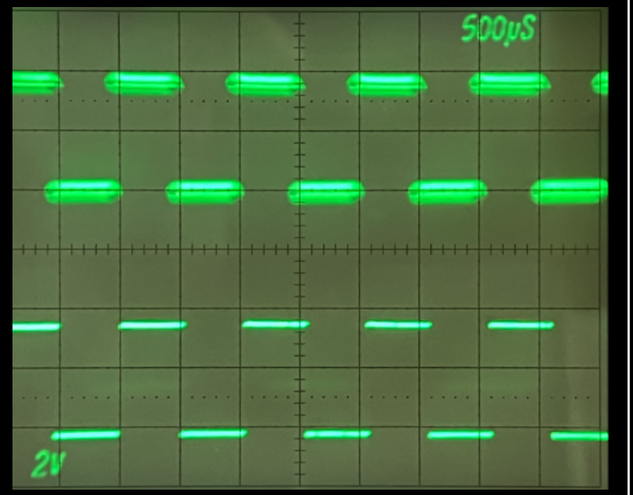
As you can see, things are less complicated than they seems, at least in theory.

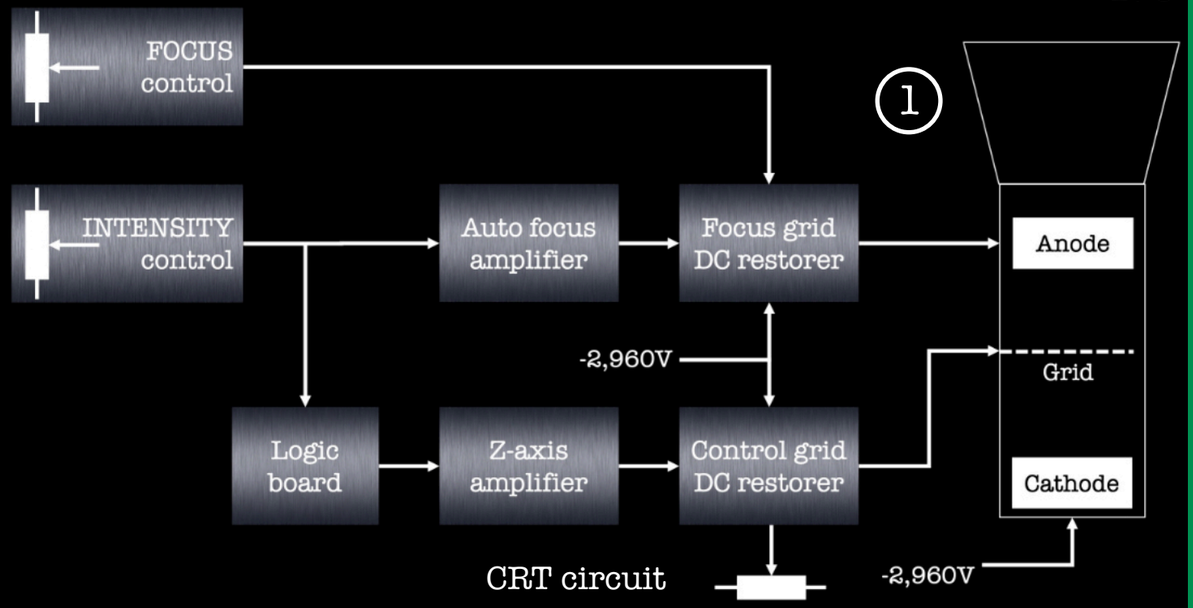
The case of 7844

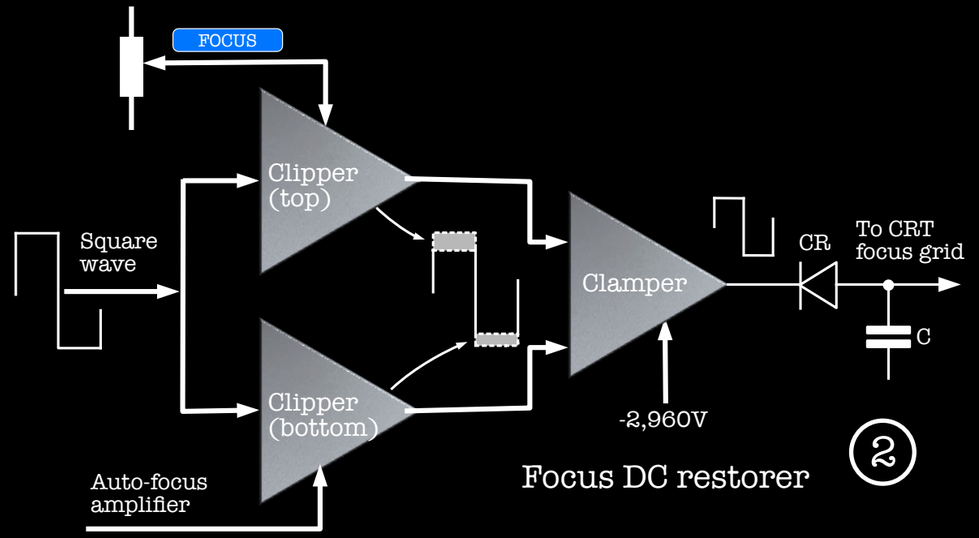
Most of what we say here has a general value and applies to many Tektronix oscilloscopes. My interest for this topic arose however from the wish to fix a strange phenomenon of my 7844: the trace is good and well defined, but, increasing the INTENSITY, at a certain point it does not get brighter but loses the focus. That is not properly the effect of a "gassy CRT", that should show two intensity peaks.

I dedicated a lot of time to this problem, without getting out of it. I checked all the voltages, finding them very similar to my 7904, that has almost the same circuits, but a brilliant intensity of the trace (see later for the voltages, they could be useful also for you) . The last beach is to replace the CRT; perhaps I found one and will keep you informed in the next editions.

In the photo, on top beam I raised the intensity to show you the problem. The two beams behave similarly.



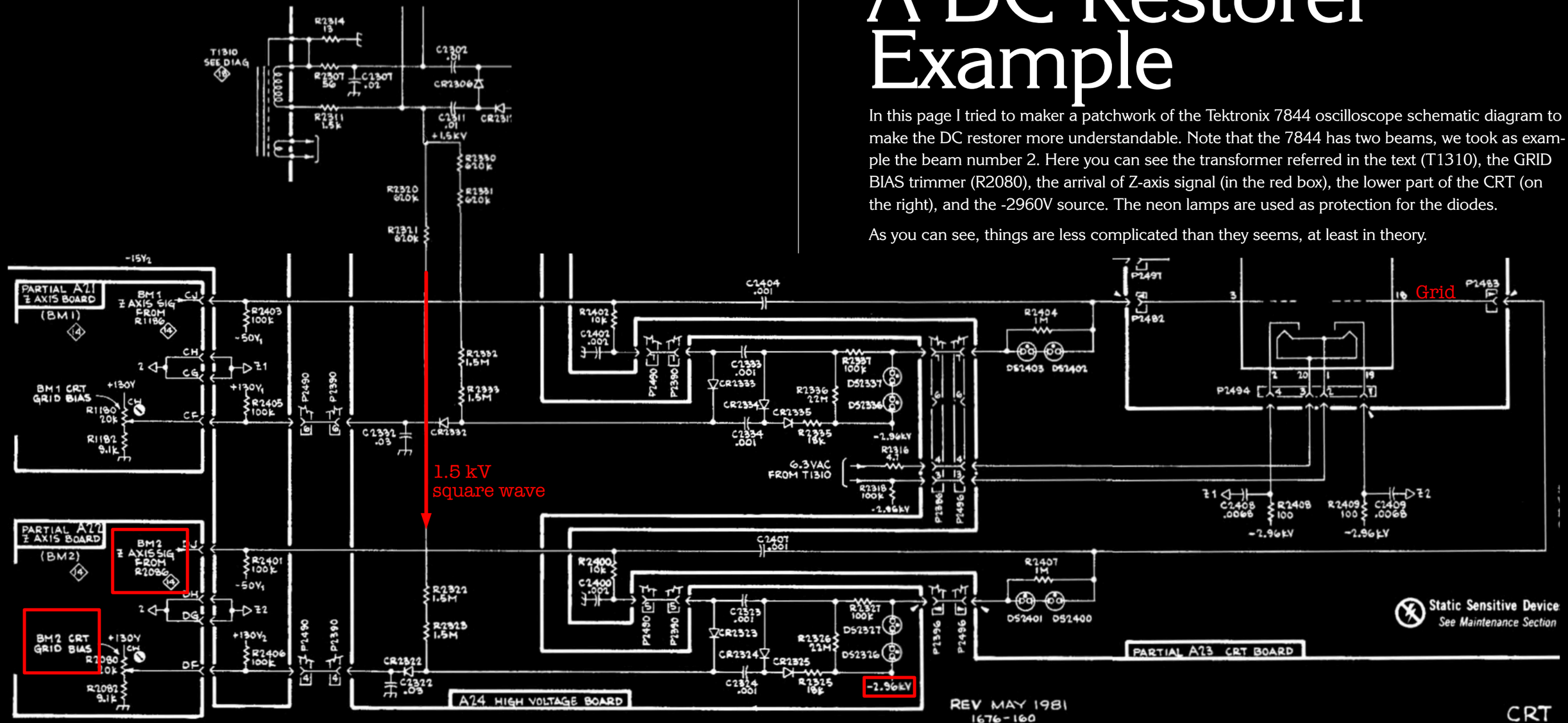




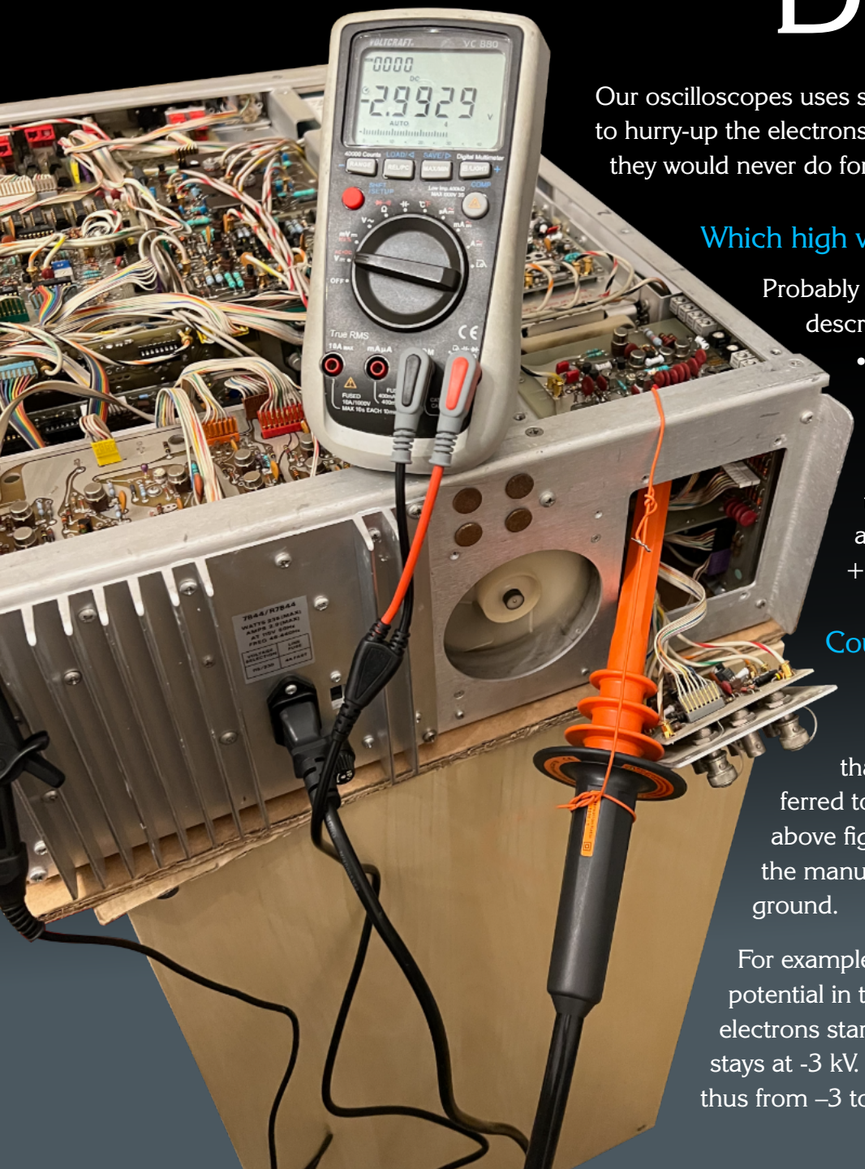
A DC Restorer Example

In this page I tried to maker a patchwork of the Tektronix 7844 oscilloscope schematic diagram to make the DC restorer more understandable. Note that the 7844 has two beams, we took as example the beam number 2. Here you can see the transformer referred in the text (T1310), the GRID BIAS trimmer (R2080), the arrival of Z-axis signal (in the red box), the lower part of the CRT (on the right), and the -2960V source. The neon lamps are used as protection for the diodes.

As you can see, things are less complicated than they seems, at least in theory.



Dealing with High Voltages



Our oscilloscopes uses some very High Voltages (HV) to hurry-up the electrons and force them to do what they would never do for us.

Which high voltages?

Probably all the oscilloscopes that we describe here use two kind of HV:

- cathode, grid and anode potential: in the range between -2kV and -3kV;
- Post-Deflection Acceleration (PDA): this is more variable, and goes from +5 to +21 kV.

Counting volts

As correct, Tektronix catalogs report the PDA value that the electrons see, i.e. referred to the cathode, while the above figures are those reported in the manuals, and so referred to ground.

For example, the 7904 uses a +21 kV potential in the front part of the CRT, but electrons starts from the cathode, that stays at -3 kV. The acceleration value is thus from –3 to +21 = 24 kV.

Measuring High Voltages

How to check these high and dangerous voltages? I avoid to warn you with the usual “cautions”, just because I believe that most of the guys interested in old Tektronix oscilloscopes are not boys, and survived to a life in electronics. So, I just report some specific information that I could put together, as always also with the help of friends on the net.

HV-probes

No common VOM can measure so high voltages; a special HV-probe is required. It is better to resist the temptation of home building an HV probe, also if it is just an electrode connected to a voltage divider. Experience is also to know our own limits, and honestly I had not so much experience with HV. You could buy some suitable-voltage resistors and put them together, but you need also to build a handle, the cables etc. All that requires knowledge.

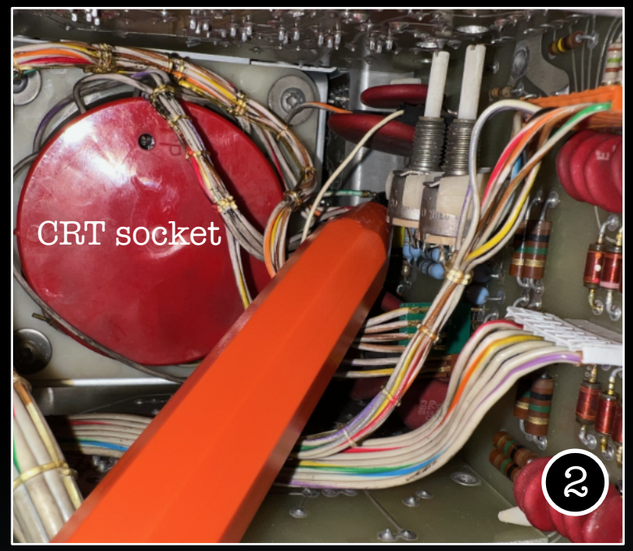
I discovered that the commercial probes are more expensive than I thought. Those from famous brands cost 800-1.000 euros. I bought one that you can see in these pages on eBay from HighVoltageShop that appeared to be however expensive (79 euros). When arrived, I changed my mind. It is really well built and inspires a high quality level. It is bigger than I expected, but it can also withstand 40 kV, so it allows also to check the PDA of any oscilloscope. It resistance is 1,000 MOhm; avoid 100 MOhm probes (or less), that charges too much the circuit and don’t disconnect the CRT for the test.

Checking the PDA value

But how to check the PDA voltage? For the cathode voltage, a test point is normally provided, but the PDA cannot always be reached. Old oscilloscopes, like the 545, have all the HV section rather easy to reach, but more modern scopes (from 7000 Series on), have the PDA voltage multiplier resin-encapsulated, while the connectors between the CRT and the multiplier module are rather sealed.

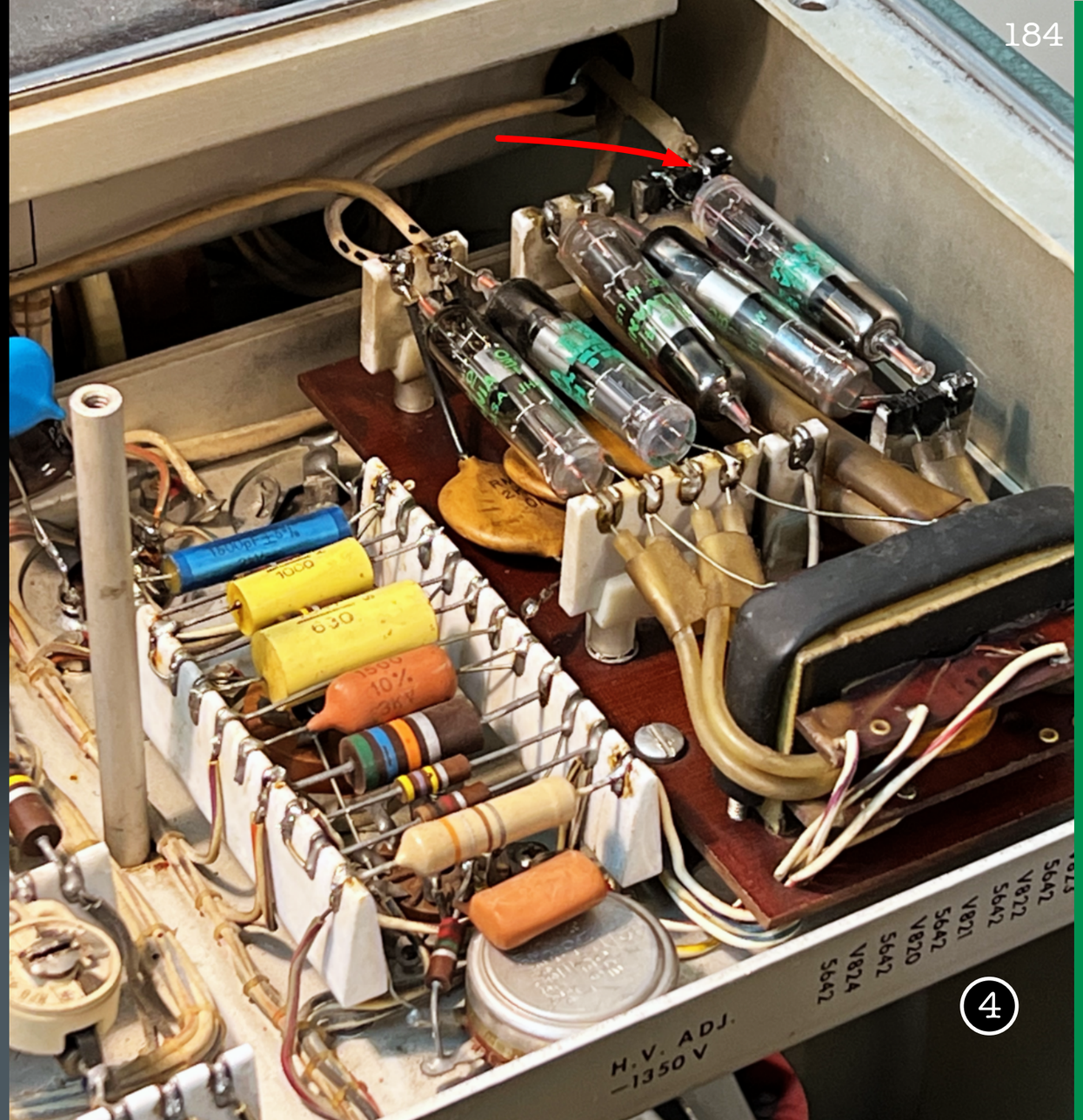
In photo 2 on the next page, you can see how I could do, with a very thin copper wire from the pipe connection. I put two plexiglass plates under it, to be sure that it could not move. When the probe get near the pick-up point, you hear a the typical and rather scaring hiss, but the reading is very stable. Remember also to keep clean the probe using Isopropyl Alcohol.





❶ A small trick to get the PDA voltage out of the connector. ❷ In some cases, like the 7844, it is not easy to get the test points. ❸ The CRT socket after removing the red cap. An incapsulated PDA multiplier module (7834). ❹ The old 545 offers a much easier access to every point of the High Voltage circuit.

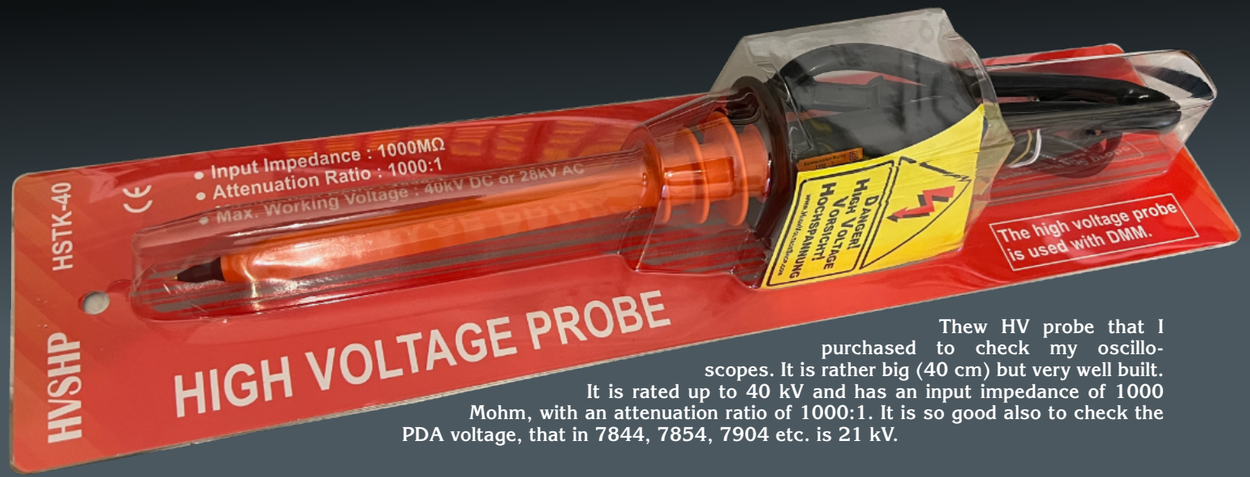




Some Values

I appreciate very much Tektronix documentation. It is only thanks to it (and TekWiki that made it available for us) that we can continue to keep alive our toys. But not all the information the we may need is present in them. For example, going around the CRT circuits to fix the 7844, I wish I had the voltages on the CRT socket. So, I tried to compare them with that that I read from my 7904, whose circuits are very similar. I prepared the following table that could be useful also for you, if you must deal with the CRT. All the values are in volt.

	7844-1	Swing	7844-2	Swing	7904	Swing
Output from Z-axis ampli	0-65		0-65		0-65	
Output from autofocus ampli	125-63		119-41		125-38	
Cathode	-2993					
Control grid top (max)	-2974	64	-2968	46	-3000	63
Control grid bottom (dark)	-3010		-3014		-3063	
Focus grid top (max)	-2018	54	-2044	71	-2163	79
Focus grid bottom (dark)	-1964		-1973		-2242	

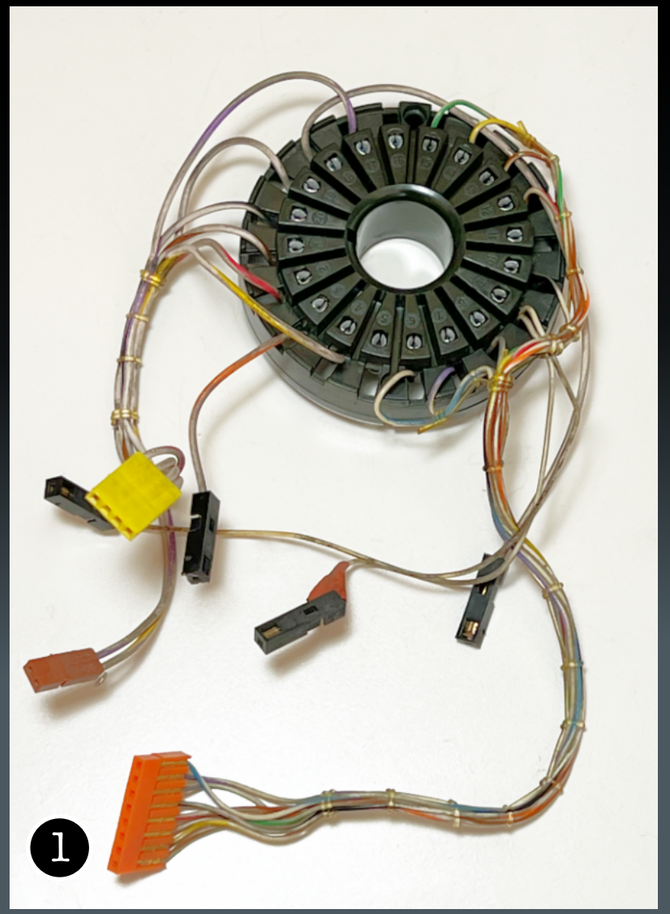


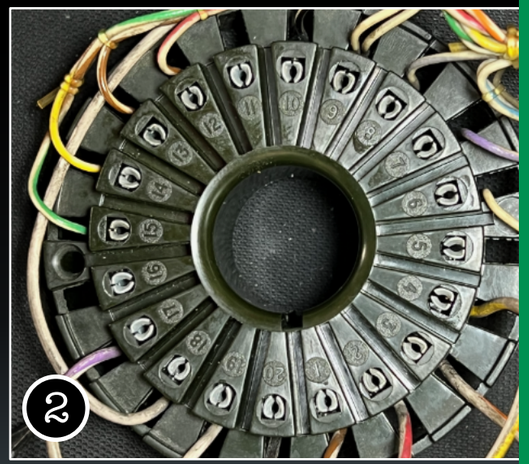
Thew HV probe that I purchased to check my oscilloscopes. It is rather big (40 cm) but very well built. It is rated up to 40 kV and has an input impedance of 1000 Mohm, with an attenuation ratio of 1000:1. It is so good also to check the PDA voltage, that in 7844, 7854, 7904 etc. is 21 kV.

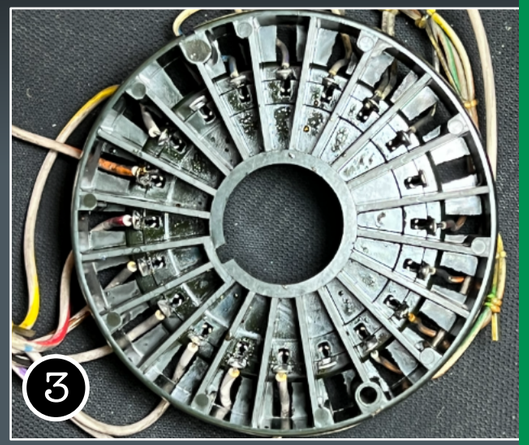
Initially, I become mad trying to get the CRT voltages in the right points of the CRT PCB, but then I discovered that the big red cap, that you can see in photo ❷ in the previous page, can be removed, even if not easily. In R7844 (note the "R"), that makes very easy accessing the CRT socket, simply removing the output signals back panel.

Removing the CRT socket was useful, not only to remove its red cap, but also to discover that some of the wires were near to break, so I resoldered them.

❶ The CRT socket assembly. ❷ The socket detail, enlarged to see pin numbers. ❸ The CRT socket after removing the red cap.









Spark of Mystery

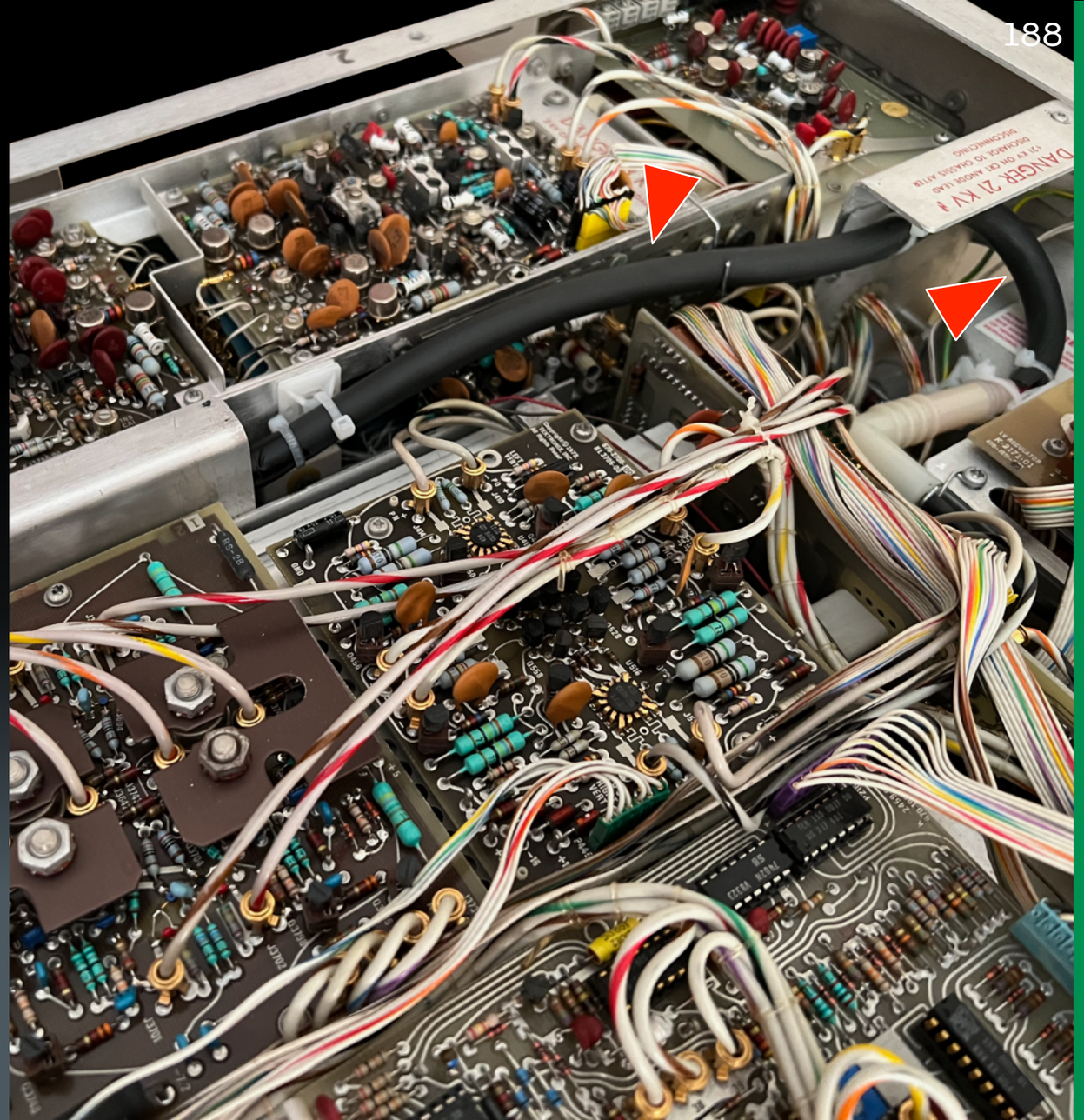
Some days ago, during some tests, I heard a spark noise coming from inside the 7844. After that, the readout system was KO. You can read the reparation story, with a deep analysis of the readout system, at page 310. The sound was of a strong spark, rather long, like “TRA-TRA-TRAC” not a simple “STIC”.

Still now, I have no clear idea of what it happened. I can only suppose that the CRT HV cable, becoming old, lost in part its isolating characteristics and produced the spark.

Today, HV cables use PTFE (Teflon), that has a dielectric constant double than free air but I don’t know which kind of wire is the 7844’s one.

Having so no ideas, I decided simply to give a better insulation to the HV cable. I bought a gasoline tube in a motorcycles shop, the black one with thick walls. Then I cut it with a cutter lengthwise, and mounted it around the HV cable. I added some supports to maintain the cable in a precise position, avoiding that it could touch other wires, as shown in the photo on the right (the red arrows point to the wrapped cable). A problem is that this cable comes from the inside of the High Efficiency Power Supply, together with other wires, so I could only work on the the exposed part of it.

On the left, the cable before being wrapped (the red one). I am not sure if that fixed the problem, but until now it did not reappear.





7000 Series

Mastering the HEPS

The power supply of the best 7000-Series, 4 slots, oscilloscopes is the black beast of the restorers. Its intelligent design makes it extremely robust, thanks to many self-protection mechanisms, which, when triggered, produces the typical “click” sound. Here you can find an in-depth analysis which can help you considerably when repairing them or to understand which external cause might determine it.



Subsection: The Black Beast

For its complexity, I call the HEPS the restorer's "black beast", but if you understand its inner working, it can become almost a doggie.

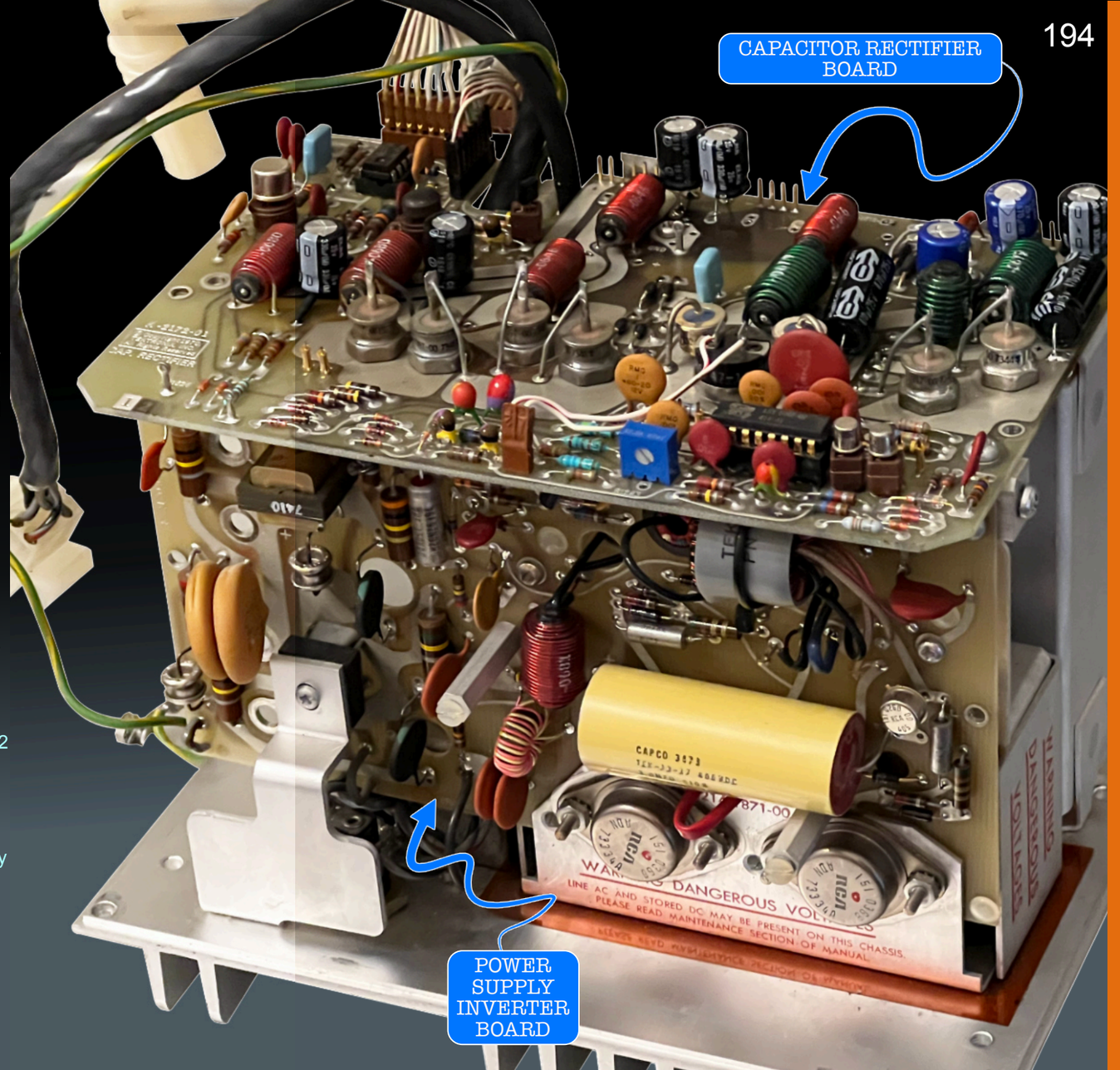
High Efficiency Power Supply

I call it HEPS, High Efficiency Power Supply, and was for me a black beast. It is the Power Supply Unit of the 7904, 7844, and, slightly revised, of 7704A, 7904A, 7854 and 7834. The 7704 uses almost the same circuit but no integrated circuits (and today that is an advantage). The information that you find below should be good for most of them. I will not report what you can find in Tektronix manuals, but I will try to make them more understandable.

What is it?

At the beginning, I thought that the HEPS was a switching power supply, but it is not exactly so. The HEPS is a big improvement, but is similar, conceptually, to the linear PSU of the various 76xx, with an important difference: in place of the normal 50/60 Hz transformer, it uses an inverter to produce a high frequency current (25 kHz) to feed it. At much higher frequency, the transformer can be smaller and lighter, while the losses due to the core material hysteresis are reduced, achieving a better energy efficiency. Tektronix described in this way the HEPS, presenting the 7904 (Tekscope Vol.3 No.4, July 1971):

> Both the low-voltage and high-voltage supplies in the 7904 are contained in a compact unit weighing just 71/2 pounds. The high-efficiency supply provides 150 watts of regulated DC at an efficiency of about 80%.
>
> A considerable savings in cost, weight and space is realized by winding both low-voltage and high-voltage transformers on a common core. The inverter, operating at about 23 kHz, drives both supplies.
>
> Pre-regulation to better than 0.5% is achieved by controlling the inverter conduction time. The control circuitry is designed to switch the inverter transistors off at the zero-voltage point on the sine wave. This eliminates the large amount of EMI normally generated by high-efficiency supplies, and reduces the likelihood of damaging the inverter transistors.
>
> Secondary regulation of the high-voltage supply is achieved using an amplifier to control only the -3 kV section of the supply.



The Black Beast

The resulting circuit is undoubtedly robust and efficient, but for me was also terribly complex, hard to understand and to debug. When I was forced to repair the HEPS of my 7844, I spent many days fighting with its complicate gears, so I decided to write these notes to make easier the job of other enthusiasts. Probably, also at Tektronix they asked themselves if it deserved all that complexity, and, in the 7603, they decided to return to the paste, with a normal transformer. The HEPS is also mechanically complex, including also the HV section in a limited and very "dense" volume, as we will see below.

Note: all the references are to the 7844 schematic diagram, if you have another scope, even with the identical boards, the reference designators are often different.

Preparing for the fight

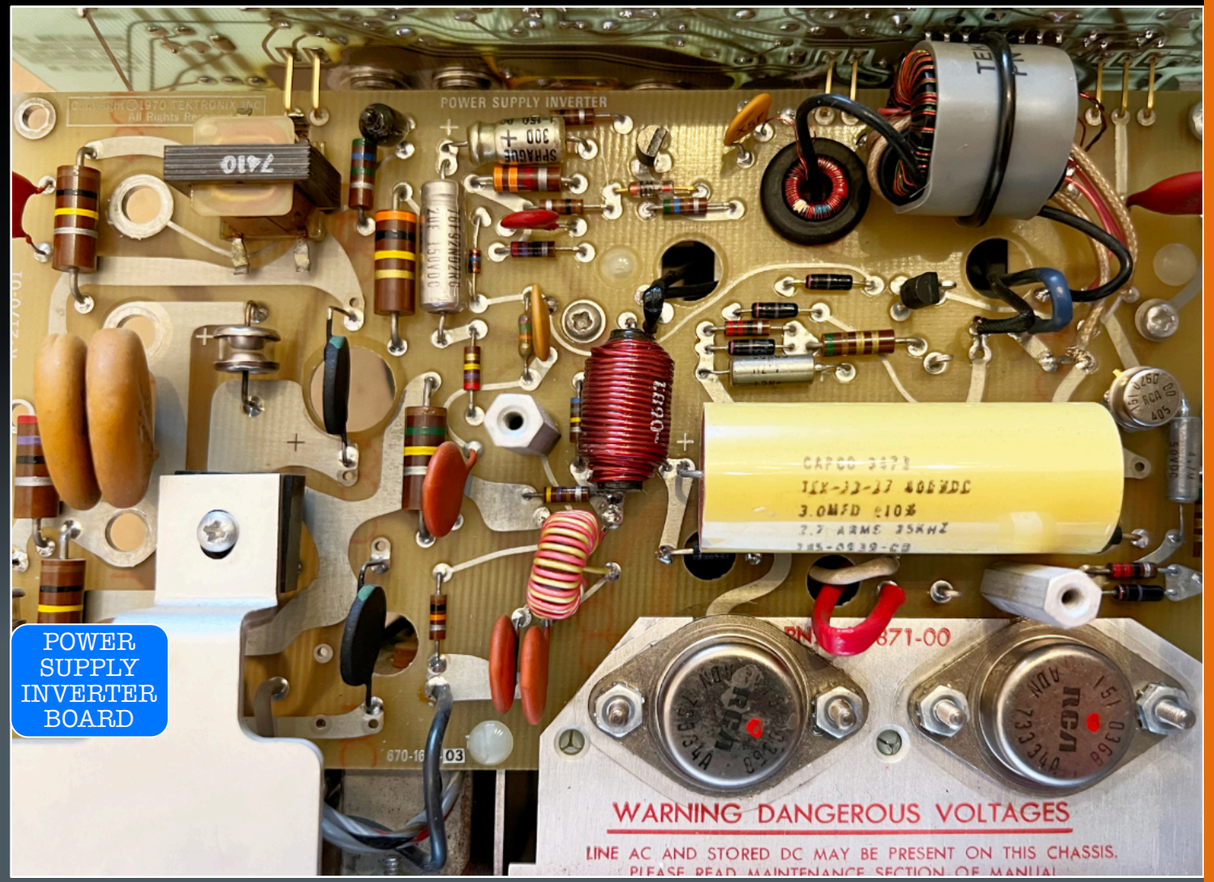
If we want to cure our HEPS, we need to arrange a proper operating table. We must afford these points:

- **disable the high voltage**: in this way we split the problem and avoid to be shocked and/or destroy other sections with errant cables;
- **eliminate unnecessary things**: the HEPS is connected to the mainframe by a big number of cables and connectors. We need to understand what and how we can remove;
- **build a dummy load** (and other adapting cables). The HEPS goes in click mode (even if not faulty) when it has not enough load;
- **create a switch replacement**, so that you can energize the HEPS also when it is on your bench.

Work calmly and take a lot of pictures during the job: they will help you in reassembling. Never think "that's easy, I will remember…". Be careful: the socketed transistors are prone to be bent or even removed if treated without attention.

When you remove the PSU, be sure to discharge the CRT, it will remain charged for a long time and will give you a shock, to punish you for having thought "oh, I will be careful…".

The black beast drawing is from https://www.vecteezy.com



Interested Boards

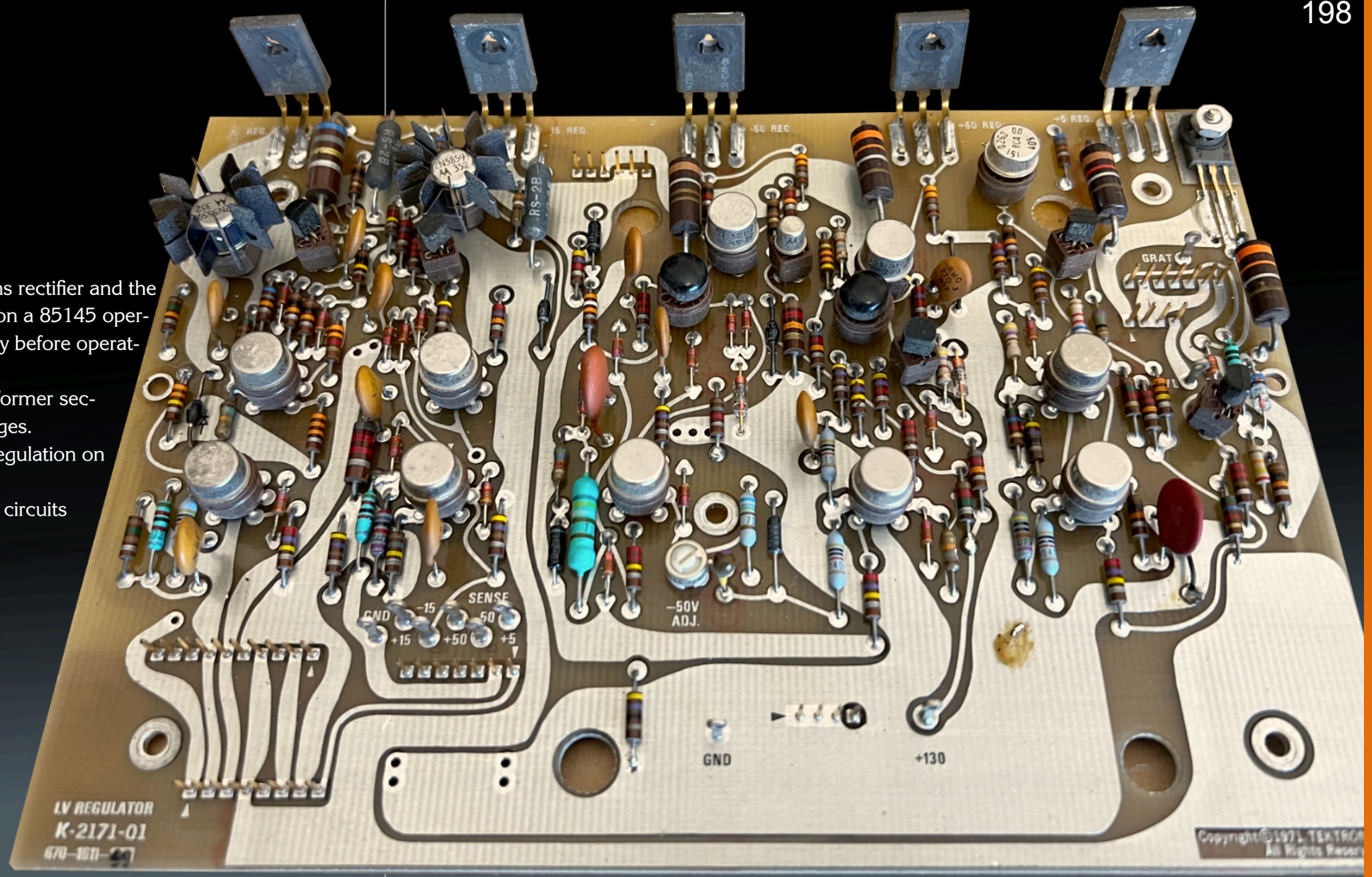
We will deal with the following boards:

- the Power Supply Inverter board (PSIB). It contains the a.c. mains rectifier and the inverter itself. It hosts also the -2,96 kV voltage regulator based on a 85145 operating amplifier. Another good reason for detaching the HV supply before operating;
- the Capacitor Rectifier board (CRB). It is connected to the transformer secondary windings and simply rectifies and levels the various voltages.
- the Low Voltage board (LVB). It performs the precision voltage regulation on the pre-regulated voltages produced by the CRB;
- the High Voltage board (HVB), aka the Death Chamber, with the circuits dedicated to produce the -21 kV and -2,96 kV voltages;
- the CRT board (CRTB), i.e. the interface to the CRT.



Here on the left you can see the voltage on a side of R1210, on the PSIB. Note that I used a X10 probe to take it, so each division is 50V.

That's normal, you can think, but they are directly referenced to the a.c. mains. Be careful!!



LOW VOLTAGE BOARD

The Low Voltage board is very similar (even if completely different) from that of the 76x3 oscilloscopes, but without the big TO-3 transistors, replaced by a smaller case (TO-127 if I am not wrong). Here also, every transistor (besides the TO-127) has its socket, (even if hidden). Note the big 2W resistors: they are the way to measure and limit the maximum current and offer the possibility to measure the current consumption, (also dynamically) measuring the voltage at their leads, using the Ohm law.

The Dreaded Click

A possible fault mode of the HEPS is the dreaded tick. Many can be the reasons that produce this problem, and knowing the general operation can make easier the solution. The Bible for HEPS repair has been the article Servicing the Tek 7904 Power Supply (from Tekscopes March 1971), and it remains. But, in my opinion, it is too synthetic and with some discrepancies, at least with my case. Reading it is a must; we will reference it as [1], and assume that you already read it (subsequently, part of it became part of the official manuals, e.g., the 1983 revision of the 7904 service manual at page 4.8, reference [2]). I will not analyze the case of the blowing fuses, on which I have no experience until now.



The death chamber

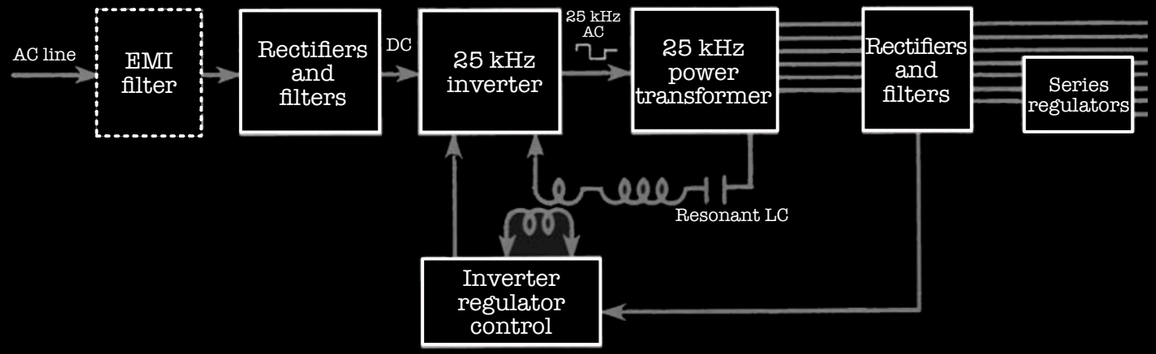
In the old electric locomotives there was a restricted area called “the death chamber”, with all the high voltage components and connections. In the HEPS there is a restricted area for the CRT +3 kV/ +24 kV voltage generation, with its sealed extra HV multiplier and the high voltage capacitors. Note the accurate construction, it is clear that they had experience in these things!

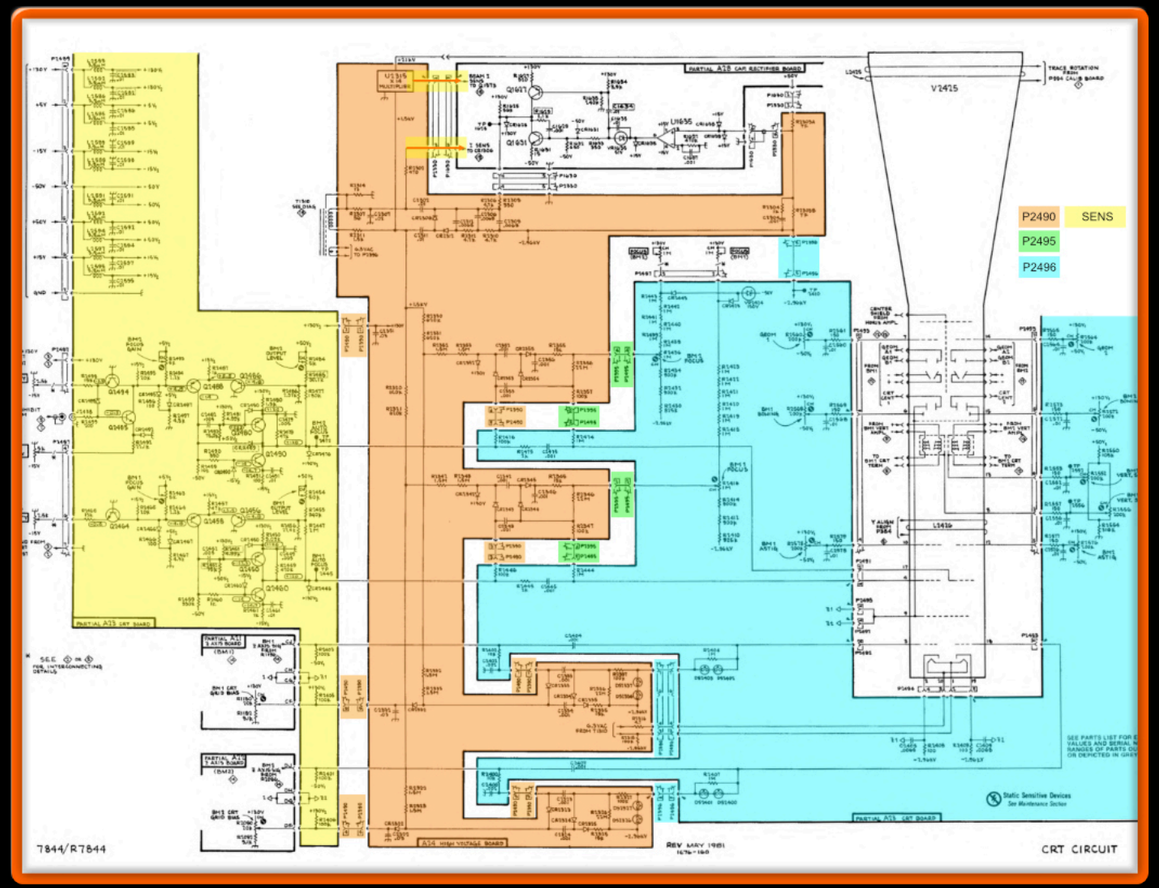
HIGH VOLTAGE BOARD

Investigation Strategy

If you already performed accordingly the [1] indications without success, In the most difficult cases, I suggest this approach, which has the purpose of splitting the problem in different segments:

- separate the HEPS from the mainframe, and discharge the CRT. I took a risk and was lucky, don't take chances;ì
- remove the Low Voltage board (LVB) and access the Death Chamber to disconnect the high voltage secondary winding (see below); replace the cover but not the LVB, we will first test the inverter without it;
- connect the dummy load to the Capacitor Rectifier board (CRB) and test the inverter, as we will explain later;
- test and fix the Power Supply Inverter board (PSIB) and the CRB, if necessary (the text continues on next page);





- remount the LVB and move the dummy load to its outputs;
- test and fix the LVB if necessary;
- restore the HV. See the following subsections for the HV circuits;
- test again with the dummy load;
- reconnect the HEPS to the mainframe and cross your fingers (note: in [1] and [2] you will find how to test the mainframe by reading its resistances at the connector).

Extracting the HEPS

Prudence

I noted that often Tektronix used module interdependencies also for safety reasons. So I was a little scared regarding the splitting of the various modules (and I had examples of these risks, e.g. don't remove P1630 with HV on) and so I analyzed the various module connections to be sure that I was not going to create further problems.

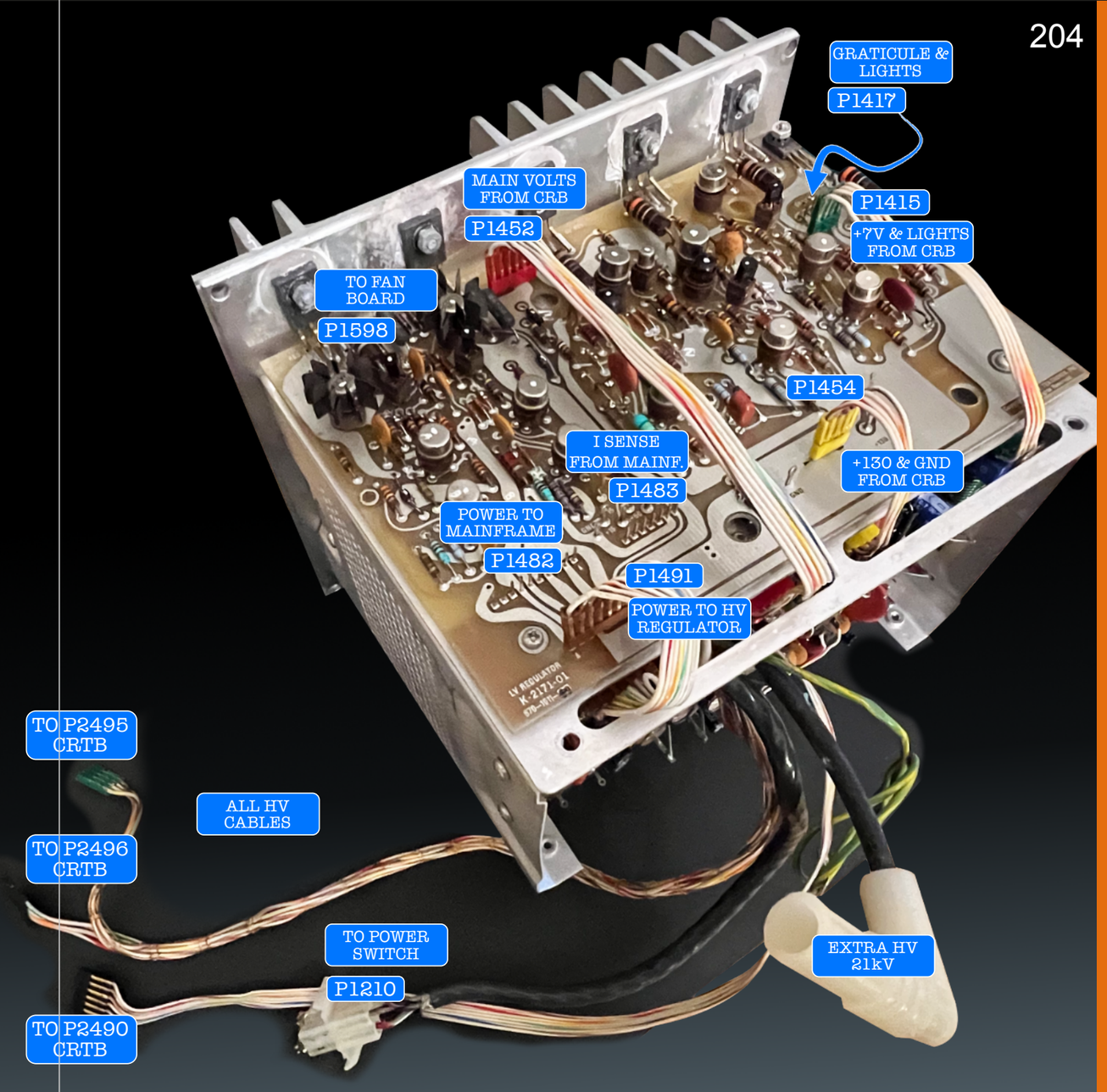
External connections

These are the connectors from the HEPS to the mainframe:

- P1598 on LVB, 2 poles, just to supply the fan;
- P1417 on LVB, , 7 poles, power supply toward the mainframe, for the graticule and the other lights;
- P1482 on LVB, 10 poles, main power supply output toward the mainframe;
- P1483 on LVB, 7 poles, current sense inputs from the mainframe;
- floating flat cable toward P2490 CRTB, 7 poles, from HVB to CRTB;
- floating "sausage" cable toward P2495 CRTB, 4 poles, from HVB to CRTB;
- floating "sausage" cable toward P2496 CRTB, 7 poles, from HVB to CRTB;

The schematic in the previous page shows the HV connections, enhancing the interested board.

Note on P2496: normally all the connectors use the same color encoding as resistors. P2496 is an exception, because it is used for high voltages and "jumps" some pins. You must know it because a mistake here can be highly destructive. Its pinout is this, and colors ignore not used pins: 1 - brown; 2 - not used; 3 - red; 4 - orange; 5 - yellow; 6 - not used; 7 – green.



Remove all

For our purposes, all these connectors can be removed with the following exceptions:

- P1482 must always be connected to a load (i.e. the mainframe or the dummy load); failing to do that you have no damage, but simply force the HEPS in the click mode;
- P1483 lines must always be connected to the corresponding lines on P1482. The HEPS voltage regulators, like other Tektronix power supplies, don't check internally the voltage they produce, but has separate sense lines for each voltage. In this way, the regulator can take in account also voltage drop due to the wire resistance and have so a better regulation "at destination". The connection point between the current and the corresponding sense wires is normally on the Main Interface board (those where the plug-ins are inserted and where is also a 10 uF capacitor for each power line). Never switch the HEPS on when the current and the sense wires are not connected together. Failing to do so, you can get damages. The LVB test points are on P1483.

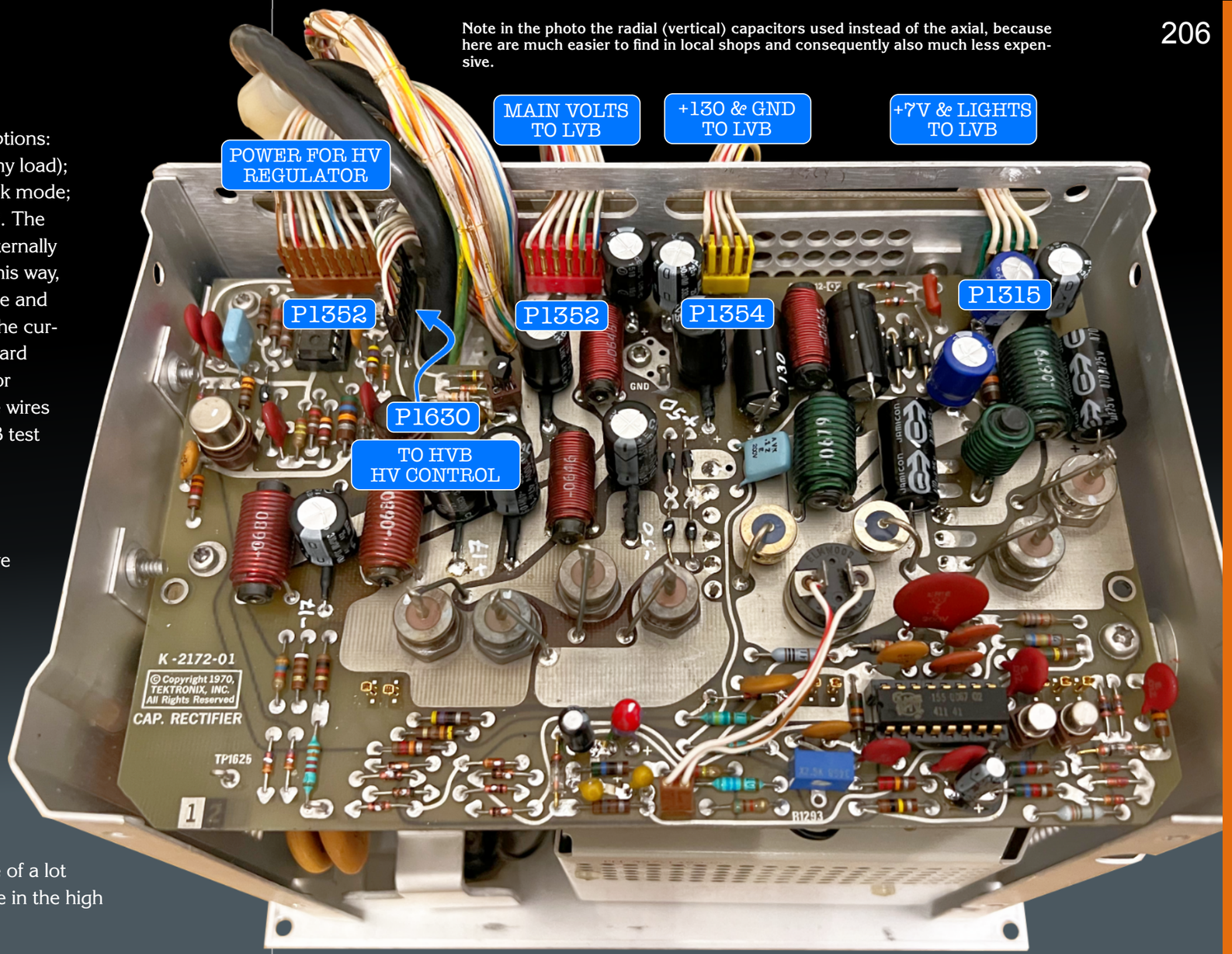
Internal connections

To complete the picture, let's talk of the connection inside to the HEPS. We have the following links:

- P1354 (PSIB) to P1454 (LVB) carries the 130V and GND connections to the LVB;
- P1352 (PSIB) to P1452 (LVB) carries the main voltages connections to the LVB;
- P1315 (PSIB) to P1415 (LVB) carries the +7V (used to produce the +5V) and the +5V for the lights to the LVB;
- P1391 (PSIB) to P1491 (LVB) carries back to the PSIB some stabilized voltages used for the -2,96 kV regulator;
- P1630 (PSIB) to P2330 (HVB) used for the 2,96 kV voltage control.

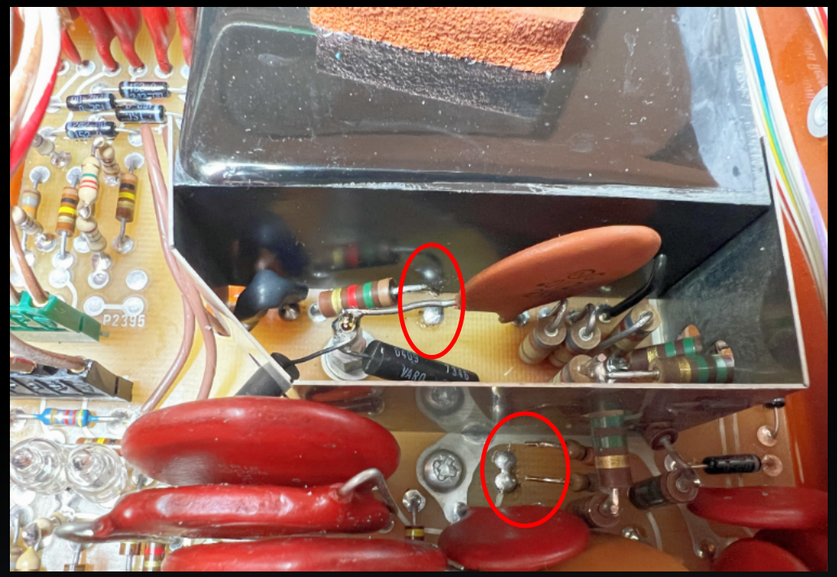
Never detach the last two when the HV is enabled. I did it, and I heard the noise of a lot of strong discharges. Clearly, the lack of the voltage regulation determines a rise in the high voltages.

Note in the photo the radial (vertical) capacitors used instead of the axial, because here are much easier to find in local shops and consequently also much less expensive.



Disabling the HV

To disable the HV, you need to isolate the HV transformer secondary winding. Open the “death chamber” (see photo here on the right) and disconnect one side of R2314, R2507 and R2311. One or two are not enough. Leave them so that they do not discharge. Removing the HV cables is not required, unless you want to work more comfortably without them. When you resolder, clean thoroughly.

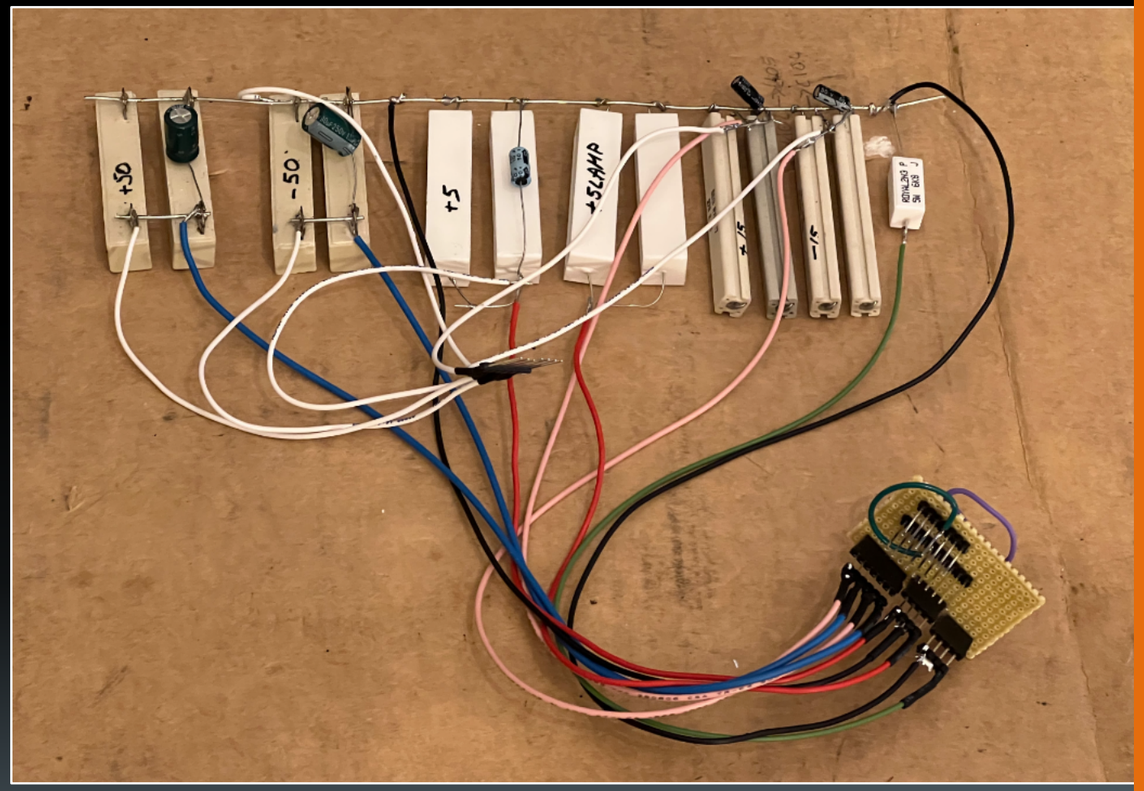


The dummy load

Resuming, at this point we have removed the LVB and disabled the HV. I suggest you to short the a.c. mains wires that go to the panel POWER switch and apply an external (bipolar) switch to control the power up of the HEPS (see a photo some pages forward). Before starting to operate, we still need the dummy load. You can follow this document or proceed as you prefer. In the photo you can see mine, not very professional indeed… but built in a very short time; I will build a better one soon. I did not use an heat sink because normally you need the load just for few seconds.

I suggest a small modification, that in my case demonstrated to be essential: add a 10 uF capacitor, of suitable voltage, in parallel with each the loads. See the whole story later, when we tell about LVB reparation.

I endowed mine with connectors ready for the flats from the PSIB, i.e. to replace the LVB as seen from the PSIB. Then I built an adapter to use it also as a load for the LVB.



Again about the dummy load, don’t do like me, and don’t use “lighter” resistors. The HEPS must be rather heavily charged to work correctly, or will go in the click mode as well as for excessive load. Use the values of the above referred article.

The Inverter

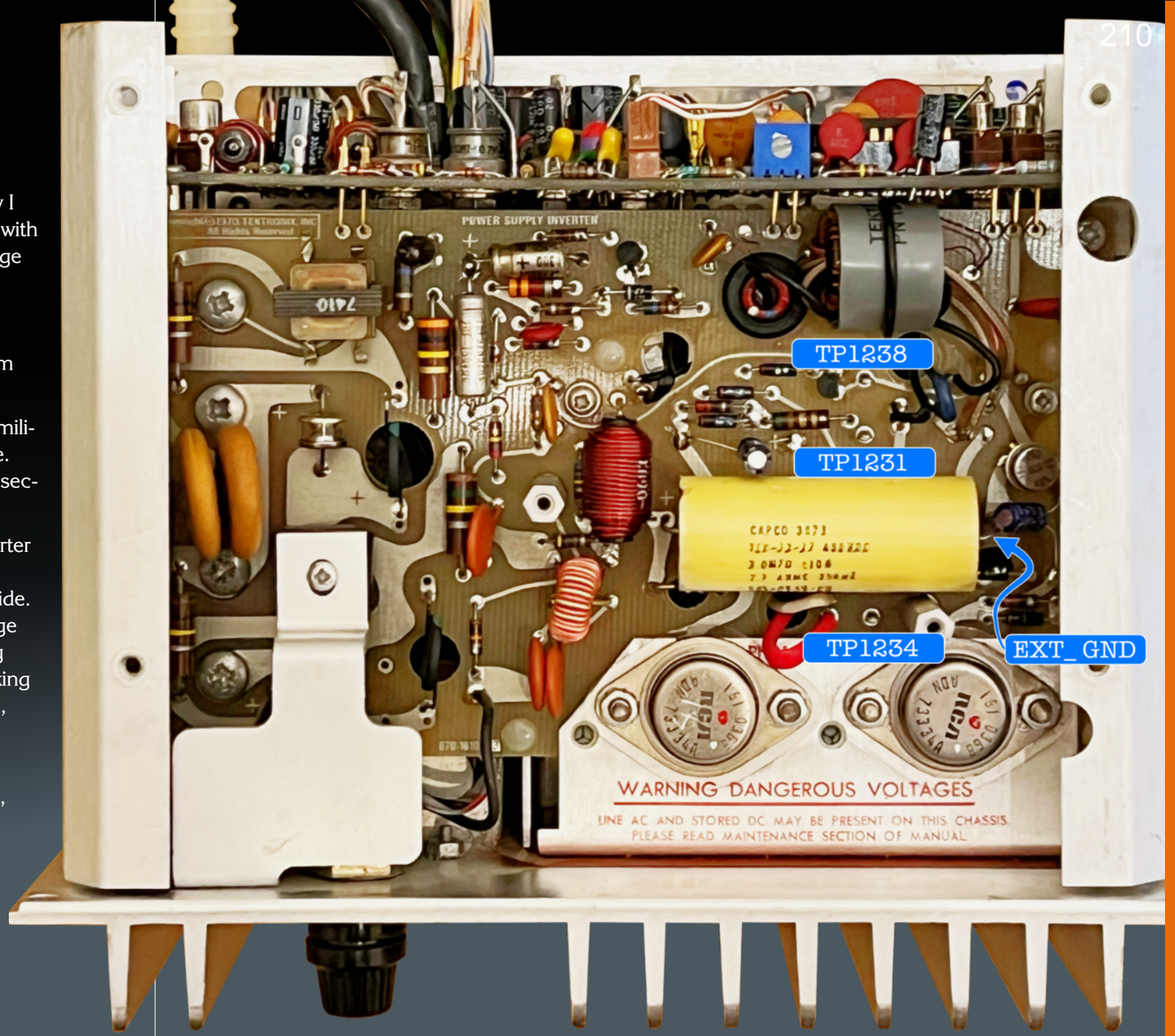
I studied very thoroughly the circuit. If I say I understood every single bit, I would lie, but surely I understood most of the necessary for trying to repair it. I had formerly the opportunity to deal with a circuit like that with the old military T-195 transmitter (see my book on military surplus at page 12), where a solid state inverter replaced the old electro-mechanical dynamotors to produce 1,000V with high current capability. I could repair it thanks to the help that I received from the friend and super-expert Dr. Hugo Holden (Acornvalve on Antique Radio forum). Back to the HEPS, read the manual for a detailed information, but find here some information derived from the experience.

The inverter is the modern replacement of the relay (or vibrator) inverters used in old car and military tube radio: two switches that act alternatively, producing a square wave from a d.c. source. The square wave is fed to the transformer and is used to produce various a.c. voltages on the secondary winding. Our HEPS inverter is something similar, but solid state.

Kickstarter: the inverter is like a metronome; to get it started, you must pinch it. This kickstarter is composed by CR1238 DIAC, a component that does not conduce below 30V and that conduces above. It is connected to C1242, a 5nF capacitor, grounded (EXT_GND) on the other side. This capacitor is charged directly by the a.c. mains thru R1210, 300k resistor. When the voltage on C1242 exceeds 30V, the DIAC CR1238 conduces and “pinches” , via C1239, one of the big TO-3 transistor (Q1241), that stimulates the LC circuit, composed by L1237 and C1237, making things to start. From that point on, Q1234 and Q1241 alternatively conduce and stop. Q1241, when it switches, thru the CR1242 diode, keeps C1242 good, so that it no more pinches.

There are many other interesting things to know about the inverter:

- **over-voltage protection**: all the components drawn near the transformer primary (C1249, C1243, CR1244 etc.) have all a purpose: to protect the inverter from overvoltages. When C1243 charges beyond a certain value, thru the 120V V1246 Zener, it triggers the Q1248 SCR that lead Q1246 to conduction. It so makes Q1241 to close, stopping the oscillations. If you suspect something from this side, that makes the inverter not to start, check the Zener. As last beach, remove Q1246. If the inverter continues not starting, the problem is somewhere else.
- **the inverter controller U1275**, but this is a deeper theme, that we will afford next.



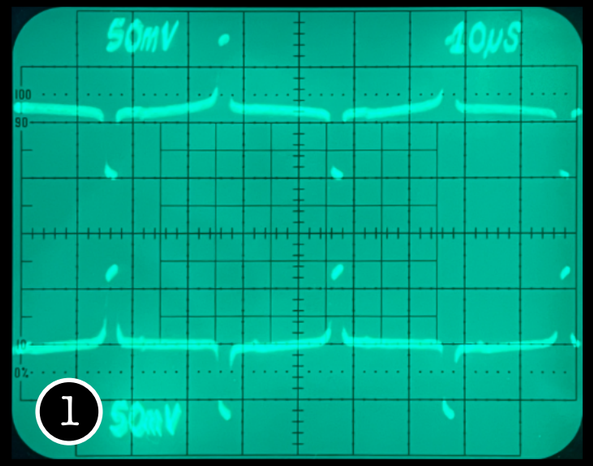
The Controller IC

The old car radio inverters operated free run, at the frequency established by the circuit constants. The HEPS inverter has instead two control "**levers**": one to control the inverter resonance frequency, and therefore the output voltages; the other is the emergency brake, to stop the inverter completely. But who drives the levers?

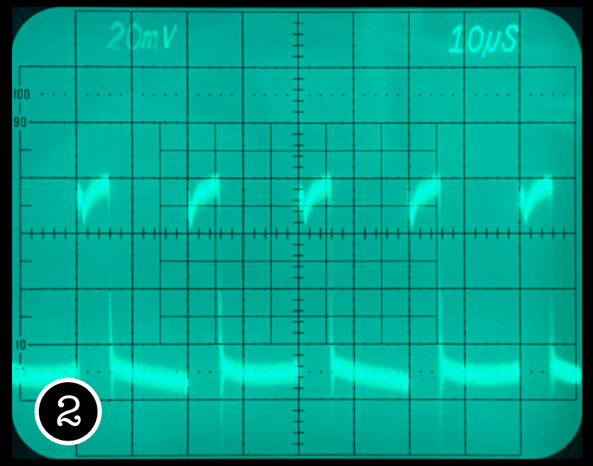
Tektronix designed a genial analog inverter controller in the custom IC 155-0067-02 (U1275), in as few as 16 pins, that performs various important tasks:

- it monitors the inverter phases, so that ordering the transistors to switch only at the zeroes of the sine wave (pin 10 and 11, PHASE TRIGGER);
- it monitors the output voltage (pin 15, E-SENSE) and controls the transistors, adjusting the oscillator frequency to stabilize the output voltages (pin 9, BASE CONTROL DRIVE);
- it monitors the alarms, to pull the emergency brake (pin 8, INVERTER STOP) when needed.

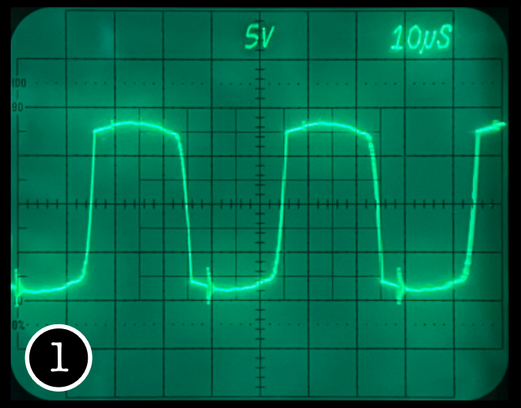
NOTE: all the oscillograms reported in this section were taken with X10 probes, that had not the sense ring, so all the V/div reported on the 7633 screenshots must be multiplied by ten.

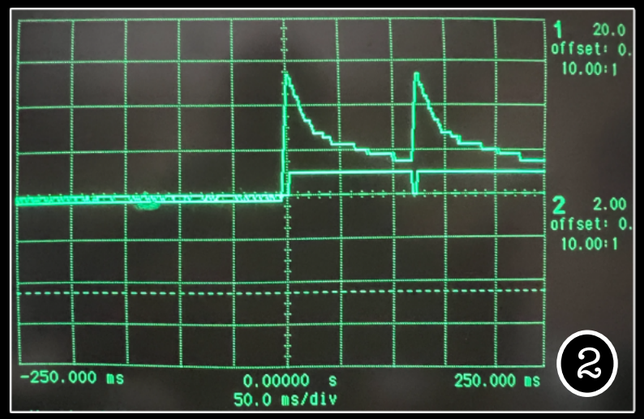


❶ The PHASE TRIGGER input signals (pins 10 and 11). This is a sample of the main transformer T1310 primary current, taken via the small T1235 transformer. It is used also for monitoring the output voltage (pin 15, E-SENSE).



❷ The BASE CONTROL DRIVE output signal (pin 9), that gives a pulse every half cycle, so every 20 us (50 kHz frequency, the double of the inverter frequency).

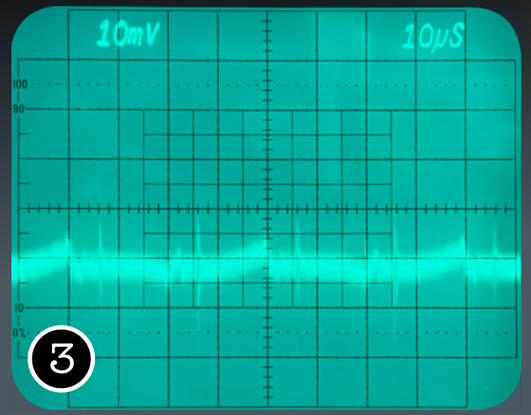


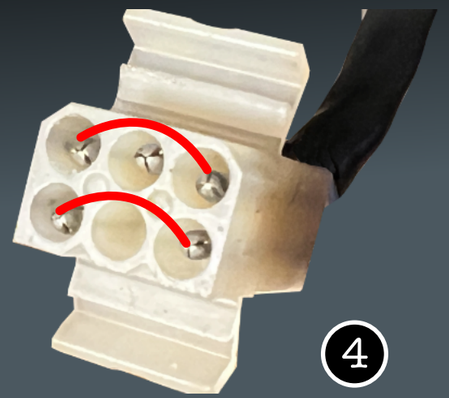


❶ The test point TP1244 in my scope is not physically present, so I took this signal on the cathode of CR1244, where the test point should be. It is the voltage on the T1301 main transformer primary winding. The shape is not a perfect sinusoid but it is not bad. Note the glitch at the beginning of each horizontal segment. I believe that it is the instant where the BASE CONTROL DRIVE pulse ends. ❷ The INVERTER STOP signal in case of a fault. On the upper trace, the +50V voltage. Something is wrong and the brake is pulled. ❸ The I-SENSE input under normal operation conditions. ❹ To allow the 7844 HEPS to switch on without the mainframe, you need to bridge the J1201 connector as shown.

There are two kind of alarm inputs that the IC can monitor:

- I-SENSE (pin 13): it monitors the feedback voltage and decides when there is an over- or underload, and, in case, issue a STOP command on pin 8. This signal can be as low as 200mV;
- BAL-SENSE (pin 2), this name was rather inappropriate and was subsequently changed in FAULT SENSE. It is normally used to monitor the high voltages, via I SENS and BEAM I SENS. We will discuss again later of these signals.

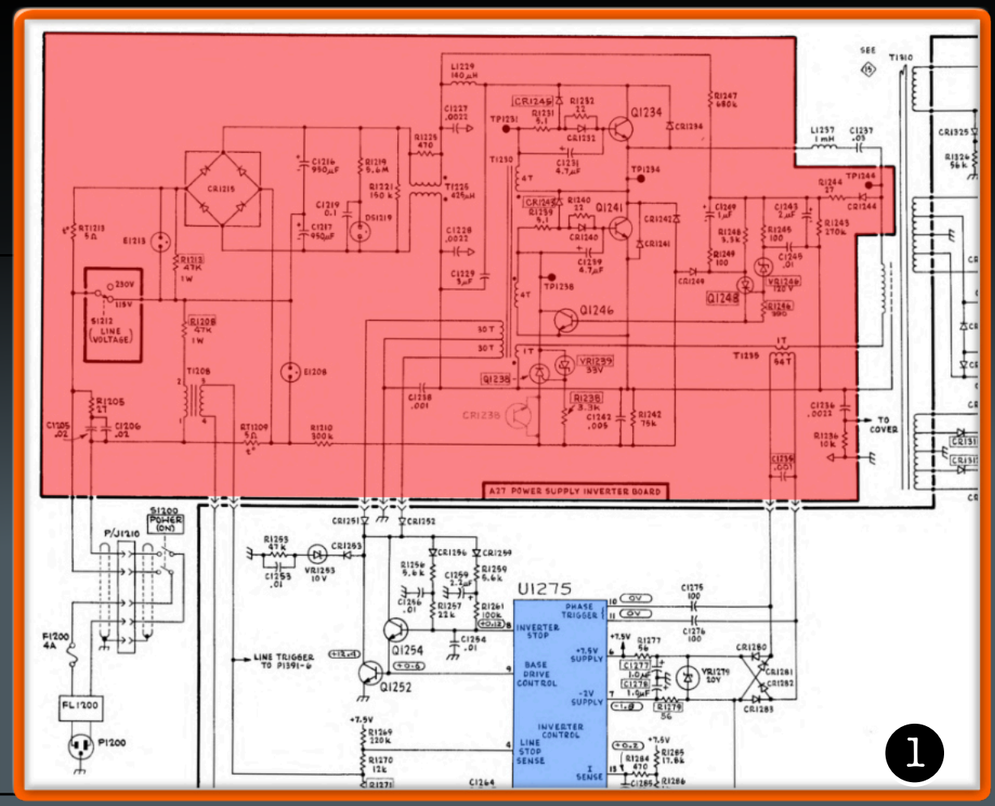




The Red Zone

In the inverter, you can distinguish two zones: one upstream of the transformer, and the other downstream.

- the upstream part, lets's call it the "red zone", has a separate ground (in today schemes we would call it EXT_GND), directly connected to the a.c. mains.
- the downstream part, i.e. the part on the mainframe ground.



❶ The red zone is the part of the inverter circuit that is insulated from the mainframe ground, and is referenced to a separate ground that is directly connected to live a.c. mains (and thus very dangerous).

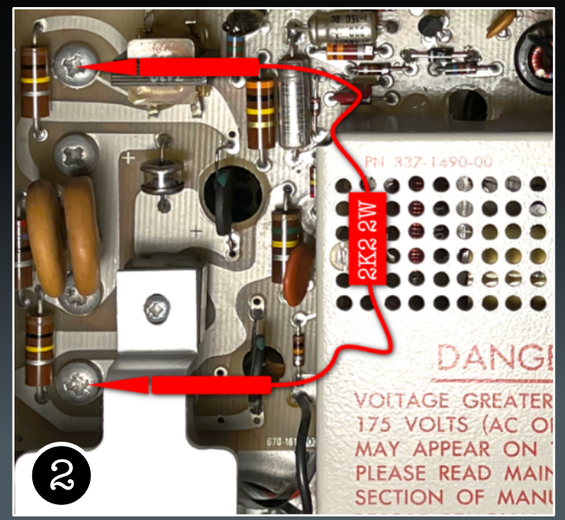
Safety Cautions

Some warnings

Going to practice, I don't like to sermonize about safety; nobody of us is a boy, and, if you like a Tek scope, you must be expert enough. But in this case there are some peculiarities , and so I make an exception:

- the high voltage to the inverter is generated directly rectifying the a.c. mains (a different wiring is provided for 115 or 230 V operation). The inverter stops **immediately** when you switch off the power supply, but the filter capacitors **remain charged**. Furthermore, being the inverter stopped, the capacitor charge lasts even longer. A neon lamp on the Power Supply Inverter board (PSI) blinks until the charges drops below 80 volts. Build a tool with two VOM probes and a 2k2, 2 W resistor to discharge the capacitor when you must put your hands there. See the photo reported above.





❶ The photo here on the left shows the safety lamp, that quickly blinks when the voltage on the main rectifier filter is above about 80V. It is well hidden inside the HEPS but it use is intended for the qualified maintenance personnel only. Remember to discharge these capacitors. as explained in the text. ❷ A useful tool: with a 2K2, 2W resistor and two old VOM probes, you can build a tool to discharge the big electrolytic capacitors that keep their high voltage (320 V) for long time. With it, you must short the two screws shown in the photo.

- **grounds:** never connect the test oscilloscope probe alligator to the red zone EXT_GND, unless you have an insulated, battery operated scope. The best point where to get EXT_GND is on the 3 μF 400V C1229 capacitor on the Power Supply Inverter board, on the side nearer to the board edge. If you touch this ground, obviously is like to touch the live power outlets at home…

With the HEPS, producing serious damages is very easy, and double attention is required. Every time you do something, before powering up, think twice what and why you did it.

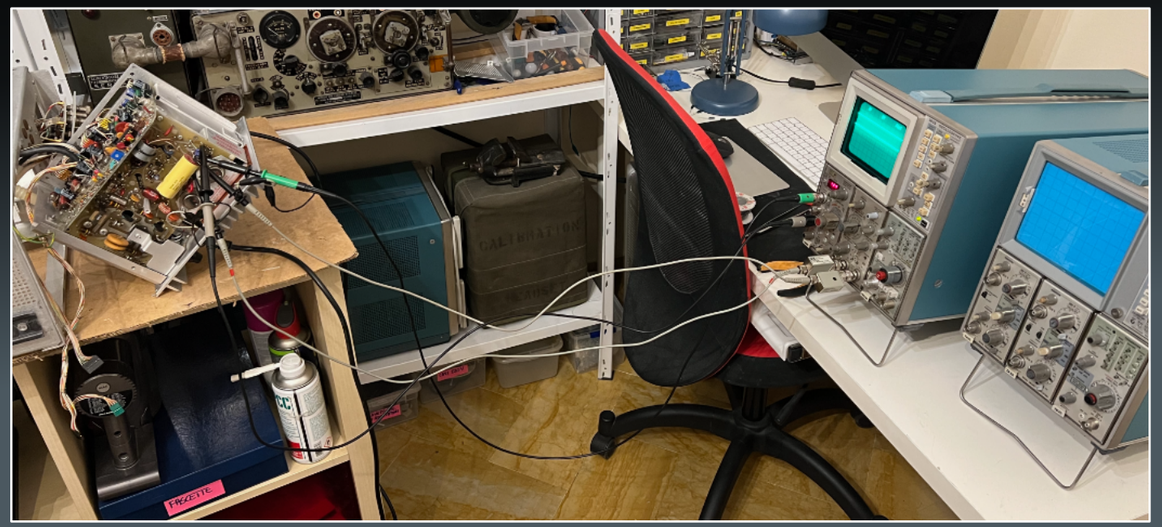


Investigations

Investigating the inverter

As we said, investigating the red zone is not easy and requires non-conventional weapons. I found a way (maybe that everybody already knew it), using my 7633 CRT storage scope, with differential vertical amplifiers. I own a 7A13 and a 7A22. Each of them allows to produce one trace, so I had available two traces for my tests. The trick is to use two probes per trace, one connected to the EXT_GND and the other to the point you want to watch (the probes' ground alligator can be connected to the metal frame). In this way you are out of the EXT_GND, but you can see the red zone signals in the normal way. Without that, I never could succeed repairing the HEPS.

BACK TO WORK. In this photo below, the 7633 that I used for investigating the R7844 problems. I started with the HP 54502A DSO, using the 33 for the differential amplifiers only. But as I proceeded with the work, I realized that I tended to use the Tek more and more. In my opinion the analog scope is much more suited to sniff the wind. The DSO, when is at its limits, just show meaningless points. With the analog, it seems me that you can more easily understand what it is happening. I like to think that the 7633 is happy for being at work again after so many years, and not just a collector's item. Note how the 7633 looks proud, while the 7603 silently observe the scene, with a touch of envy for the 7633's memory....



The dreaded sound of silence

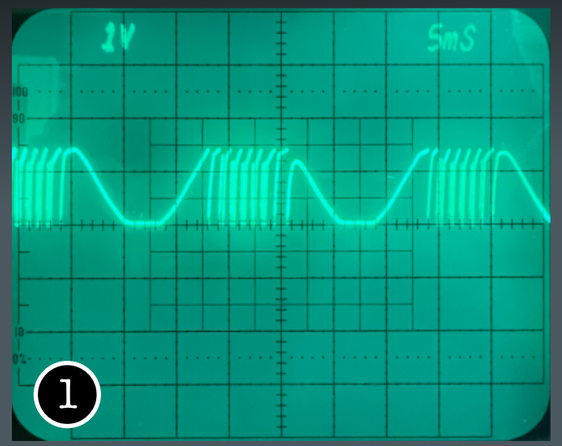
Trying to fix the click problem, I stumbled in another problem: the sound of silence, i.e. the absence of the click, with the fuses neither burning, nor having any other sign, besides the absolute flat calm. I was devastated by that: I have been paying the maximum of attention to work correctly, but after few checks in the PSIB, I had taken a step back instead of forward.

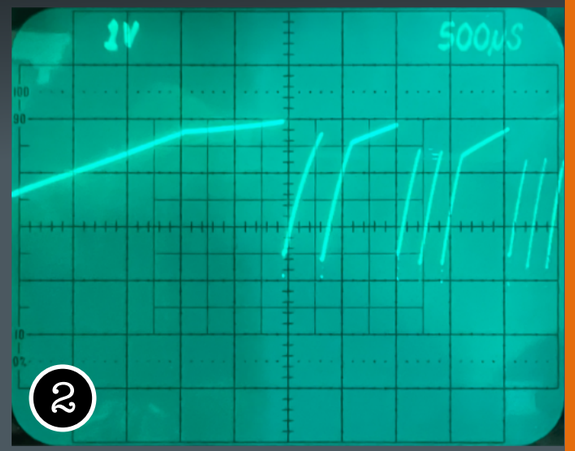
So, the only way was trying to understand what was happening. After some tests, I discovered that the poor inverter was not dead: the **kickstarter** was doing its duty, and the inverter was trying to start (see photos below).

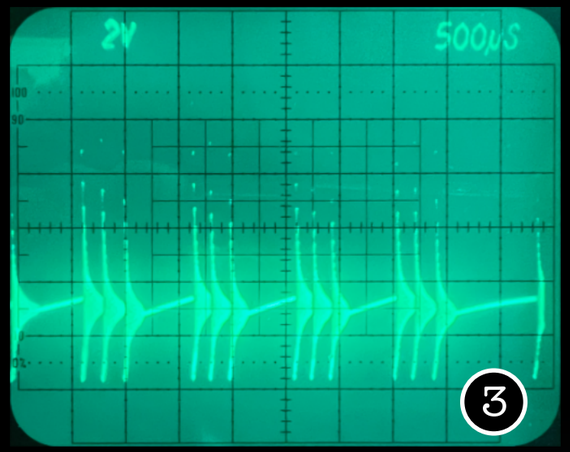
The first idea was that the **over-voltage protection** (described above), rightly or wrongly, was stopping the inverter. After many thoughts and checks, I decided to risk removing this safety control. That's rather easy, just remove Q1246; in this mode you just trim the nails to the over-voltage protection. Nothing to do, the inverter didn't want starting.

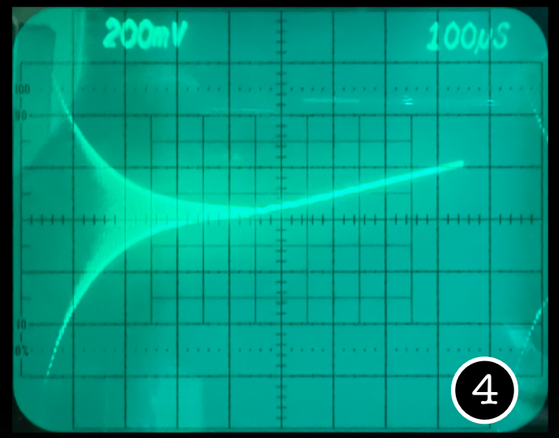
Then I asked myself if an overload on the secondary could be the cause, but on the secondary windings side there was no activity at all.

❶ The photo here on the left shows the voltage at C1242, the kickstarter. The photo ❷ on the right is the relative to the same pulses but with a faster time/div. They allow to see that the kickstarter is working. The voltage on the capacitor increases until at about 30 V, it triggers Q1241, as it should, and few cycles start (Q1241 closes and discharges C1242). But the inverter does not start.









❸❹ Again the non-starting inverter. Both photos are related to TP1234, with different time/div and amplitude. The attempt to start an oscillation is evident.

The next suspected was the controller IC. Could it be the cause? After again many thoughts and checks, I concluded that it must be not guilty, for the simple reason that, not starting the inverter, it had no energy to start up. It was in a coma, so it could not be the murder.

I had checked every diode and transistor (and even tried exchanging the two TO-3 transistors), so it could be only an answer: the problem arises in the zone of those that we called the "**levers**", the controls commanded by the IC, to manage the inverter. Because the IC was in a coma, the problem had not to be in the way the levers were operated, but in the levers themselves. The decision was then:

- first just swap Q1252 and Q1254, they are identical, and see what happens;
- then try to remove both and also the IC, as a prudence.

I started the swap and I had a flash. Why, if they are identical, are they placed in different positions, when their sockets are in the same position? Simple, my dear Watson. The donkey that helps me in these jobs (see below), had checked these transistors, but replaced them in the wrong way in the socket… NOOOOO! Do you want to see that...

Yes, I correctly reset the transistors, and the no longer dreaded, but now beloved click started again.

Music

By the way: if click is dreaded, and the silence too, which is the ideal music to the HEPS-repairer's ears? You will get used to it: two or three clicks, and then the silence. It is normal that in the beginning the HEPS goes in protection and that few kickstarter hits are always required.

Investigating the inverter controller

OK, now I could allow myself the luxury of hating the click sound again. I had not yet the dummy load, and so I just tried to investigate the mythical IC controller. Apart from everything, it deserves a praise. Tek succeeded building a fully analog microcontroller, very well performing, with the sixties technology, it's not little. I studied all the pins and already presented you a description of them above; now let's go in deeper details.

Disable BAL SENSE input

One idea that I had, has been to disable the BAL SENSE input, that is used for monitoring the following signals:

- BEAM I SENS - this signal is produced autonomously by the sealed module x14 multiplier (in the Death Chamber), that rises the -2.96 kV voltage to 21 kV, in a short an alarm for the extra high voltage circuit;
- BEAM I SENS - this is produced by the 2.96 kV voltage regulator composed by the operational amplifier U1635 and related components on the PSIB.

Both signals are fed to the PSIB via P1630, that links them from P2330 of the HVB, where they are combined together, and reach the IC pin 2 BAL SENSE. If one of them is wrong, the inverter controller U1275 raises an exception and stops the inverter.

In this loop there is also another participant: the S1305, a big thermostatic switch that opens if the board temperature exceeds 205 degrees (Fahrenheit, I suppose, i.e. 96°C).

Considering that we have put to off the HV, we can safely disable this input alarm, just removing the S1305 connector and strapping its pin 2 to ground on the PSIB, as shown on next page. In this way we can eliminate from our investigations another suspect (don't forget to restore the right connection before enabling again the HV!).



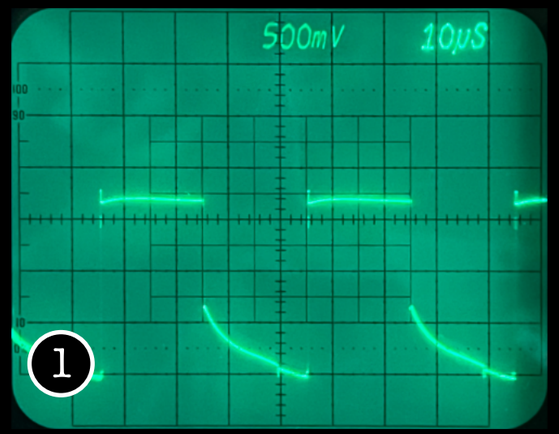
A simple way to disable the BAL SENSE alarm. A wire jump from pin 2 of the thermal switch connector and EXT_GND.

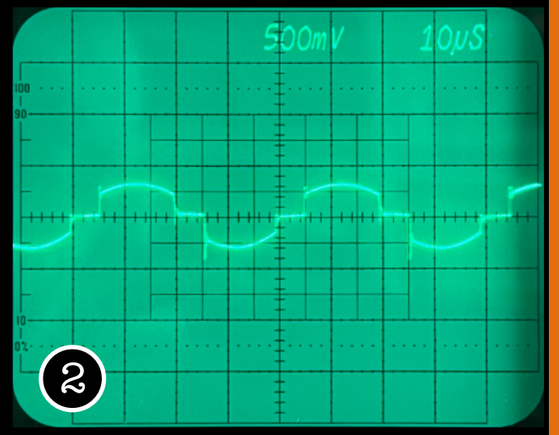
The CRT alarms

In this job, I reconstructed the smoke loop of BEAM I SENS, that is very convoluted. I report it here, should it be useful for you:

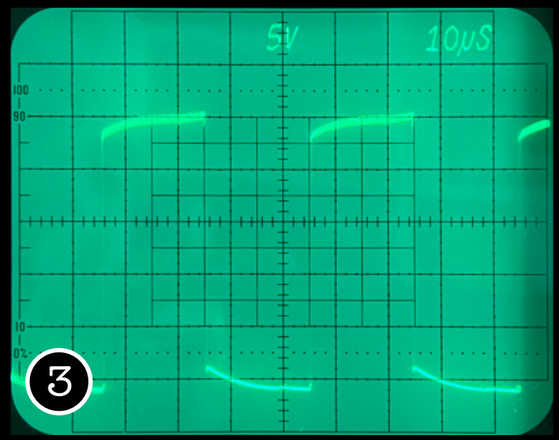
- HVB (R2203) P2330, pin 3 to PSIB P1630, pin 2 ⇨
- ⇨PSIB P1391, pin 8 to LVB P1491, pin 8 ⇨
- ⇨LVB P1483, pin 1 to Main Interface board P83, pin 1 ⇨
- ⇨Main Interface board piggyback pin E to Logic board piggyback pin E ⇨
- ⇨Logic board J331 and J572 to Z-axis amplifiers J1131 (beam 1) and J2072 (beam 2 and read-out), to limit the beam intensity if at dangerous levels.

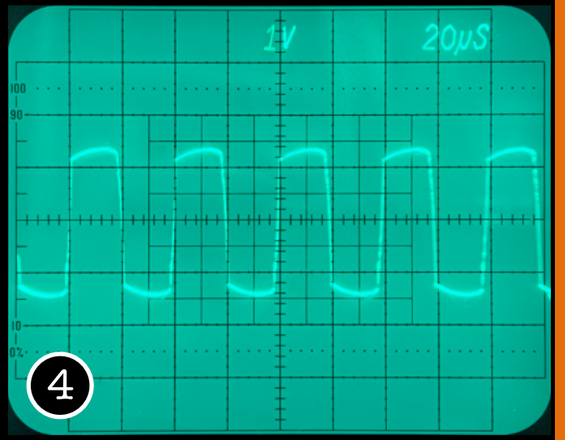
More Oscillograms



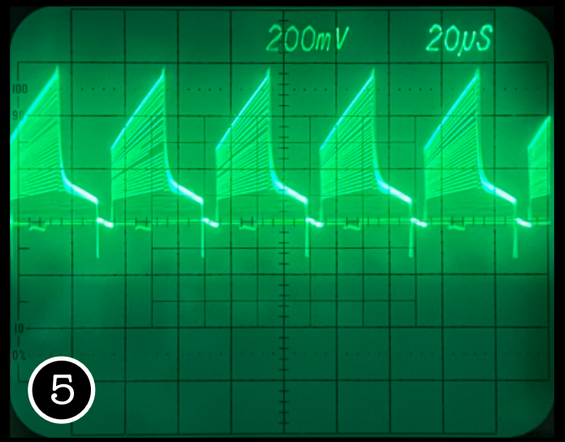


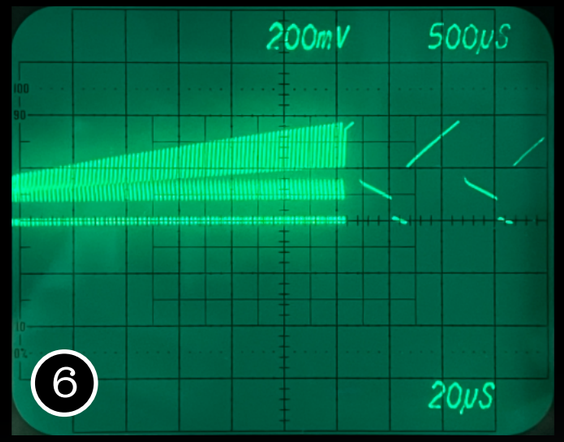
❶ TP1234 in normal operation conditions. ❷ TP1238 in normal operation conditions. Remember that all these diagrams have the amplitude value to be multiplied by ten.





❸ TP1231 in normal operation conditions. ❹ The AC from T1310 transformer to the +5V rectifier.





❶ C1242 in normal operation conditions. ❷ C1242 again, in mixed mode scan: the first part has been scanned at 500 s/div, the second at 20 s/div. I explained to myself this strange behavior: C1242 is discharged for the action of CR1242, but the voltage on the collector of Q1241 is continuously variable, so the cut starts from the actual point to zero.

The Capacitors / Rectifiers Board

We did not speak too much about the CRB (apart of the controller IC) because it is almost straightforward. A problem here is rather easy to find, and to fix.

Probably it's a good idea to take the opportunity of a recapping. Today very good electrolytic capacitors are easy to find, inexpensive and much better that the old ones. I decided to use higher capacitance values, about 30÷50% bigger, they are small enough and I can not see any contraindications for doing that.

Check also all the diodes and the transistors.

The LV Board

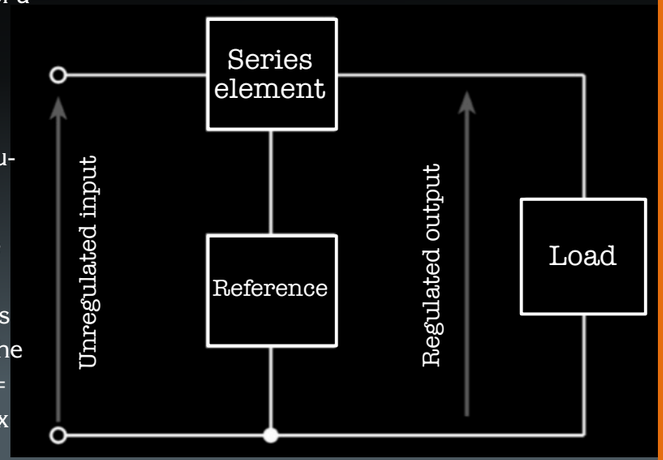
More difficult than it seems

OK, now we hopefully repaired the inverter section and refurbished the CRB with new capacitors. We are ready to afford the LV board, not so easy as you could think.

Already in the seventies, when you wanted a linear regulator, you just chose the voltage and the polarity, and you could buy a 3-terminal linear voltage regulator IC, ready to run (7805, 7812, 7912, etc.). At Tektronix, they probably preferred to rely on an internal design, also to create voltages reciprocally dependent and very carefully protected. Whatever the reason was, with this LV we have to fight. Let's remember the base principles of a linear regulator.

Basic circuit operation.

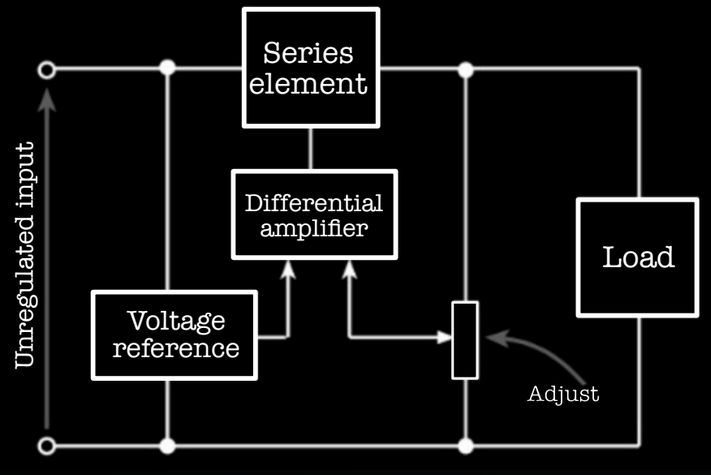
That here on the right is a basic series regulator circuit.



The input voltage is always higher than the desired input, and the current toward the load is the same. As you know, the power is given by the product of the voltage times the current. For example, we could have: Vin = 15V, Vout = 5V, I = 1A. We have 15W (15 x 1) in input and 5W in output (5 x 1). And where did they go the 10W difference? Simple: it goes in heat, normally dissipated by the Series element. For this reasons, power supplies circuits like HEPS are today rarely used, preferring switching regulators that operate on a completely different principle, much better from the energy point of view, but that could also produce some unwanted electrical noise, not welcome on an instruments like ours.

Coming back to our case, the HEPS follows this scheme.

The differential amplifier monitors the output voltage at destination, thru the sense inputs. Only the -50V has an adjustment potentiometer, because all the other voltages are in some way dependent on the -50V.

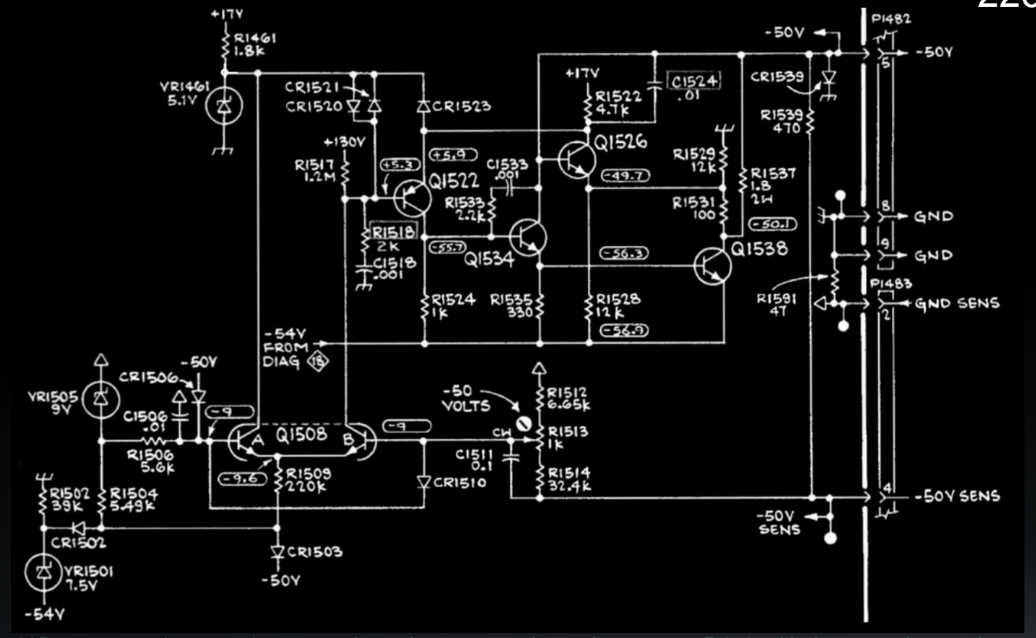


-50V Circuit from the 7844 manual

Semi-regulated -54 V from the Converter/Rectifiers circuit provides the unregulated voltage source for this supply. Transistors Q1508, Q1522, and Q1534 operate as a feedback-stabilized amplifier to maintain a constant -50 V output level. Transistor Q1508 is connected as a differential amplifier to compare the feedback voltage at the base of Q1508B against the reference voltage at the base of Q1508A. The error output at the collector of Q1508B reflects the difference, if any, between these two inputs. The change in error output level at the collector of Q1508B is always in the opposite direction to the change in the feedback input at the base of Q1508B.

Zener diode VR1505 sets a reference level of approximately - 9 V at the base of Q1508A. A sample of the output voltage from the —50 Volt Supply is connected to the base of Q1508B through divider network R1512, R1513, and R1514. resistor R1513 in this divider is adjustable to set the output level of this supply. Notice that the feedback volt age to this divider is obtained from a line labeled -50 V Sense. If the feedback voltage were obtained at the supply, the voltage at the load would not stay constant, due to the inherent resistance of the interconnecting cable between the supply and its load (as the load current varies, the voltage drop along the cable also varies). The Sense configuration overcomes this problem by sensing the voltage at the load. Since the current in the Sense line is small and constant, the load voltage is held constant regardless of the load current.

Regulation of the supply occurs as follows: If the output level of this supply decreases (becomes less negative) due to an increase in load or a decrease in input voltage (as a result of line-voltage changes or ripple), the voltage across divider R1512, R1513, and R1514 decreases also. This results in a more positive level at the base of Q1508B than that established by the - 50 V Reference stage at the base of Q1508A. Since the transistor with the more positive base controls the conduction of the differential amplifier, the out put current at the collector of Q1508B increases. This in crease in output



from Q1508B causes an increase in current through Q1522. This allows more current to flow through Q1534, resulting in increased conduction of Q1538, the

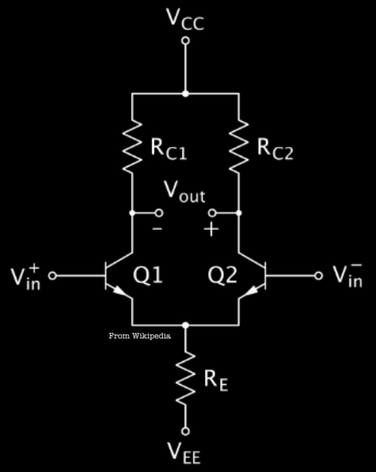
—50 V Series Regulator. The load current increases and the output voltage of this supply also increases (becomes more negative). As a result, the feedback voltage from the -50 V Sense line increases and the base of Q1508B returns to the same level as the base of Q1508A. Similarly, if the output level of this supply increases (more negative), the output current of Q1508B decreases. The feedback through Q1522 and Q1534 reduces the conduction of the -50 V Series Regulator to decrease the output voltage of this supply. The -50 V adjustment, R1513, sets the output level of this supply.

The -50 V Current Limiting stage (Q1256) protects the -50 Volt Supply if excess current is demanded from this supply. Since the load is connected to this supply through R1537, all current from the -50 Volt Supply must flow through this resistor. Transistor Q1526 senses the voltage drop across R1537. Under normal operation there is insufficient voltage drop across R1537 to forward bias Q1526.

When excess current is demanded from the - 50 V Series Regulator due to a short circuit or similar malfunction at the output of this supply, the voltage drop across R1537 increases until it is sufficient to forward bias Q1526. The collector current of Q1526 results in a reduction of current through Q1522 and Q1534 to limit the conduction of Q1538. This current limiting protects Q1538 from damage due to excess power dissipation.

Several protection diodes are also included in this circuit. Diode CR1539 prevents the output of this supply from go ing more positive than about +0.6 V if it is shorted to a positive supply. Diodes VR1501 and CR1502 supply a turn on voltage for Q1508 to start the - 50 Volt Supply when the instrument is first turned on. As soon as the —50 Volt Sup ply turns on, CR1502 turns off to disconnect the turn-on voltage to Q1508.

Differential Amplifiers



To better understand the LVB, it is advisable to remind something about the differential amplifiers. For many of us “differential amplifier = operational amplifier”, and the first name that comes to mind talking about them is uA741, the first integrated op amp. But which is the difference between differential and operational amplifier?

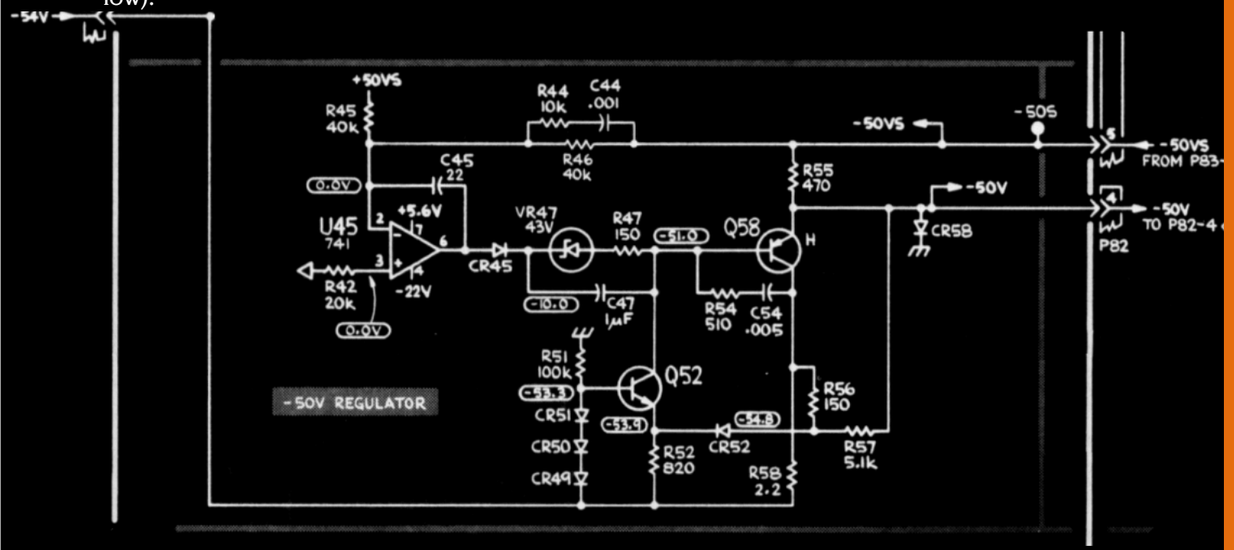
> The main difference between differential amplifier and operational amplifier is that a differential amplifier is an amplifier that amplifies a voltage difference between its inputs, whereas an operational amplifier is, in fact, a type of differential amplifier with a large open-loop gain, a high input impedance and a low output impedance (pediaa.com).

Tektronix used often often circuits based on differential amplifiers (DA), and the LVB has plenty of them. So I believe that it is not useless this little review.

Obviously, DAs are not automatically ICs. The simplest form of DA is composed by just two transistors, a configuration said “long tail”, shown in the schematic diagram here. Let’s resort to chunks from Wikipedia:

> A differential amplifier is a type of electronic amplifier that amplifies the difference between two input voltages but suppresses any voltage common to the two inputs. It is an analog circuit with two inputs Vin+ and Vin- and one output Vout, in which the output is ideally proportional to the difference between the two voltages.
>
> **Biasing**: In contrast with classic amplifying stages that are biased from the side of the base (and so they are highly β-dependent), the differential pair is directly biased from the side of the emitters by sinking/injecting the total quiescent current. The series negative feedback (the emitter degeneration) makes the transistors act as voltage stabilizers; it forces them to adjust their VBE voltages (base currents) to pass the quiescent current through their collector-emitter junctions. So, due to the negative feedback, the quiescent current depends only slightly on the transistor's β.
>
> **Common mode:** in common mode (the two input voltages change in the same directions), the two voltage (emitter) followers cooperate with each other working together on the common high-resistive emitter load (the "long tail"). They all together increase or decrease the voltage of the common emitter point (figuratively speaking, they together "pull up" or "pull down" it so that it moves). In addition, the dynamic load "helps" them by changing its instant ohmic resistance in the same direction as the input voltages (it increases when the voltage increases and vice versa.) thus keeping up constant total resistance between the two supply rails. There is a full (100%) negative feedback; the two input base voltages and the emitter voltage change simultaneously while the collector currents and the total current do not change. As a result, the output collector voltages do not change as well.
>
> **Differential mode**: in differential mode (the two input voltages change in opposite directions), the two voltage (emitter) followers oppose each other—while one of them tries to increase the voltage of the common emitter point, the other tries to decrease it (figuratively speaking, one of them "pulls up" the common point while the other "pulls down" it so that it stays immovable) and vice versa. So, the common point does not change its voltage; it behaves like a virtual ground with a magnitude determined by the common-mode input voltages. The high-resistance emitter element does not play any role—it is shunted by the other low-resistance emitter follower. There is no negative feedback, since the emitter voltage does not change at all when the input base voltages change. The common quiescent current vigorously steers between the two transistors and the output collector voltages vigorously change. The two transistors mutually ground their emitters; so, although they are common-collector stages, they actually act as common-emitter stages with maximum gain.

It seems is very interesting that with a circuit simple like this, you can achieve so many advantages. It is interesting a look forward (respect to the 7844) to the subsequent 7904A, 7854, 7834 HEPS, where the LVB has been rejuvenated, replacing discrete components with uA741 ICs (see here below).



Investigating the LVB

Repairing the LV board, we have powerful allies: the sockets, that allows us to adopt the **coward strategy**. Instead of analyzing the circuit in details, like true men do, first check every transistor, every diode and every Tantalum capacitor, with the VOM, if you have not better instruments, like the curve tracer. In the case of the HEPS, only the big transistors have no socket, and are soldered to the board. In desperate cases, however, it is not too difficult to desolder the emitter (the pin on the left) and check them also. Note anyhow that I have found also faults caused by open resistors.

I follow always first the inglorious way. It seems slow, however it could be time saving instead.

But what, if you cannot find the problem in this way? When the going gets tough, the tough get going… and if you are not tough, you must become.

Note that sometimes you follow the donkey's suggestions and you do a lot of unnecessary work. I never did it, I swear… uhm… So, right or wrong, I decided to understand if every voltage circuit was OK (I thought not, but in reality they were OK…).

By now you will have understood, that my strategy is to split the problems, so that to fight just one enemy at a time, but here the problem is the interdependencies among the various voltages.

The good news: the interdependency is partly only apparent. Many of the diodes that you see to different circuits, are there only as a protection in case of shorts or other mistakes. If you read carefully the manual, there are a clear indications regard that. This is the list of some the protection diodes (I don't pretend it is exhaustive): CR1539, CR1468, CR1589, CR1469, CR1439, CR1549.

Before going to the war

Let's reflect: what are we doing and why? Probably we have the following possibilities:

- the inverter is clicking also with the dummy load;
- the inverter does not click, but one or more voltages are wrong, or something is developing heat;
- the inverter is clicking with the LVB, but it worked with the dummy load.

The R1287 method

The inverter can click for insufficient or excessive load. So, we must understand where we are. To do that is rather easy, as described in the document [2], just check the voltage across R1287. I suggest

this procedure:

- check if the stop is really issued by the controller IC: it is easy, as we have shown before, just place the test oscilloscope probe on U1275 pin 8 (compare it with the oscillograms above);
- if not, find the problem elsewhere. If yes, check the voltage across R1287, as suggested by document [2]. In my opinion it contains an error in this point.

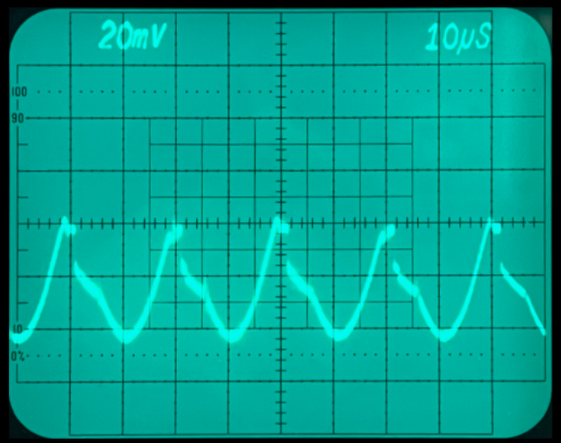
It seems impossible that the pulse duration is that described in the diagram. The frequency there is that derived directly by the T1310 transformer (via T1235), so the pulse duration should be 20 µs and not 10 ms. Also the amplitude of my HEPS is not that reported by [2] (in the oscillogram below each division is 200 mV, so the pulse is about 500 mV, not 900). Are they referring to the envelope?

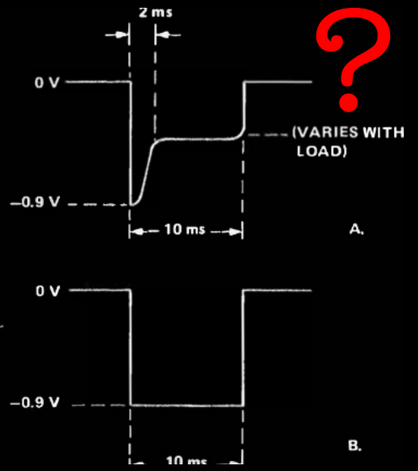
But the idea is very good: on R1287 you can read the total current produced by the inverter.

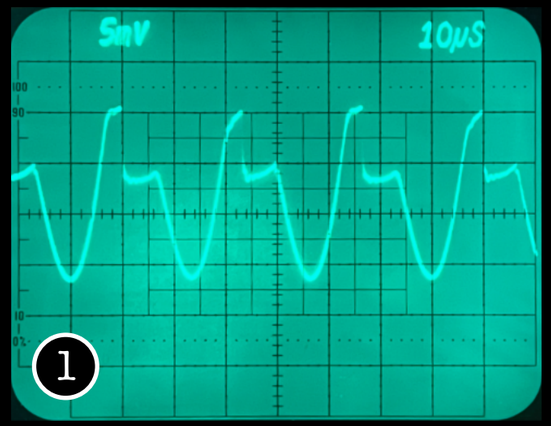
I report also, on next page, the case of a shorted output (not my fault, but of the donkey). Well, in this case we have even a lower pulse amplitude: only 150 mV. Note also the behavior seen with a slower time base. I leave to you the conclusions on the article interpretation.

The [2] document suggest also:

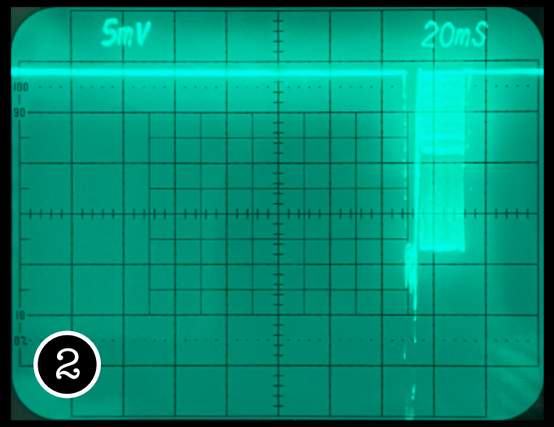
> Connect the 10X probe to each power supply at the test points (on the LVB) . Note the polarity, amplitude, and shape of the waveform present at each test point. Look for a power supply where the burst voltage is very low in relation to the specified supply voltage.







❶ Voltage drop across R1287 in condition with +50V shorted.

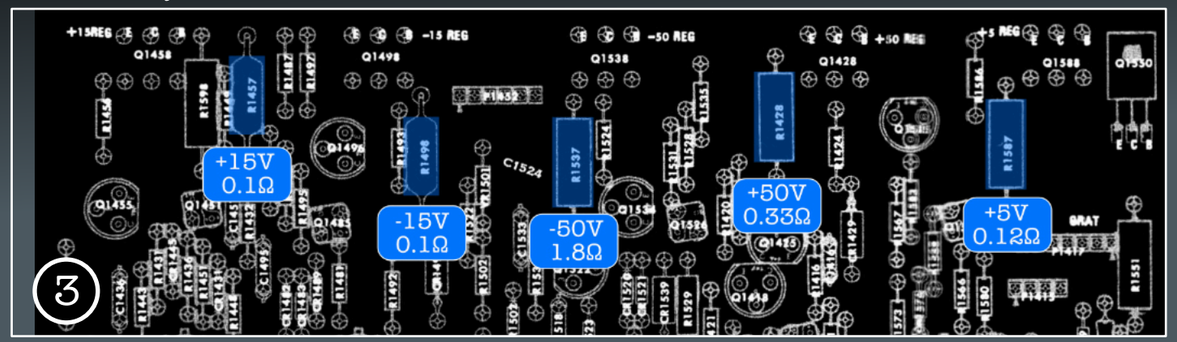


❷ The same with different scales.

Measuring each current

We have also another way to check the current absorption on the various voltages. Each voltage has a low value resistor (e.g. 0.1 ohm), used for current limiting. If you use the differential amplifier, with a probe at each end, you can easily calculate the current: I = V/R, R is known, and V is given by the differential pulse that you see on the test oscilloscope. In this way I discovered very quickly that, in my case, there was a connector inserted in the wrong way. The following ❸ picture could help you.

❸ The current limiting resistors on the LVB. The current that flows in them is the voltage across their terminal divided by their resistance value. You can use the VOM to read the average current, or a differential vertical amplifier with your scope to see the its dynamic trend.

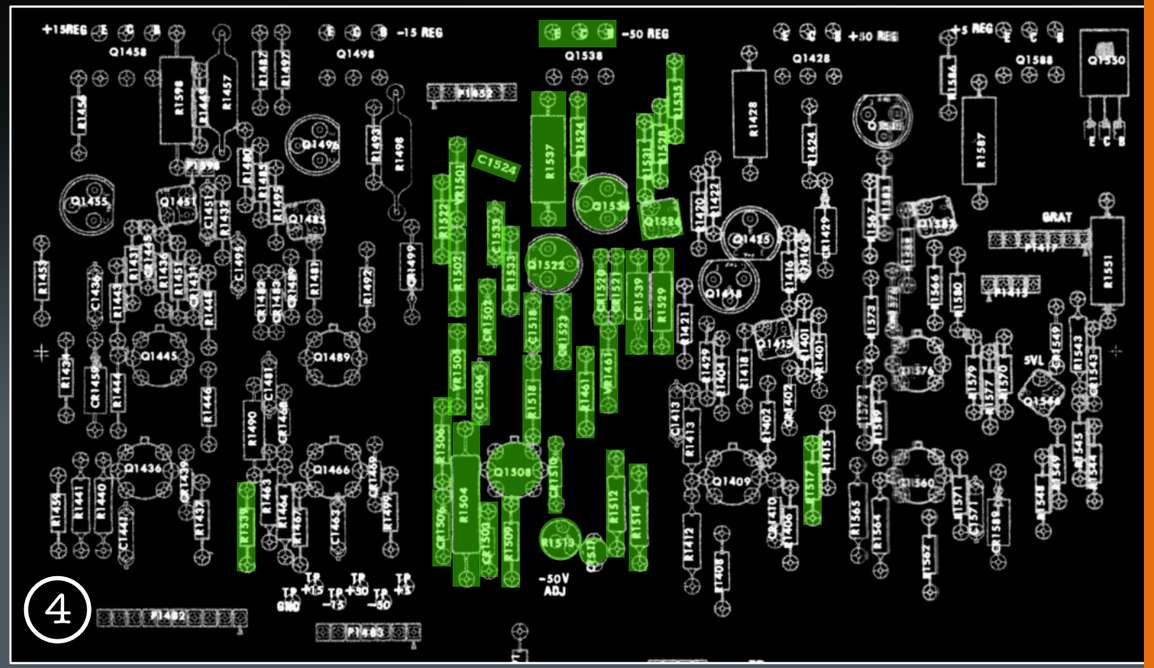


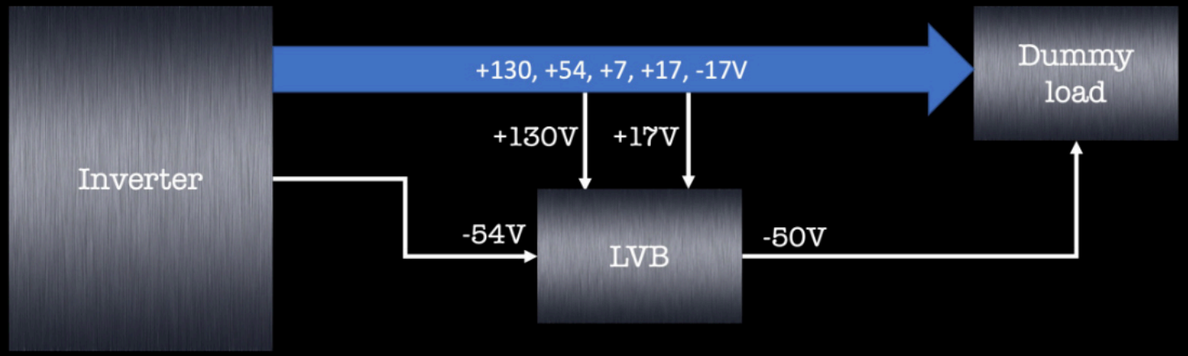
Checking the -50V

In my “understand-everything” mania, I wanted to check each individual voltage circuit. A good way to waste time, perhaps, but led me to establish some important rules. But but let's go in order.

I was in the stage when the inverter with the dummy load was operating correctly. I then reconnected the LVB and placed the dummy load downstream the LVB Again I got the click. “So its you!”, I thought, and decided to analyze the LVB. I tried in various way, without understanding too much of the problem. So I decided to try activating only one section of the LVB, inter alia the -50V section, because that is the conductor for all the others. It requires only +17V, -54 and +130, all from the inverter. So I left the dummy load on the inverter, but diverted the -54V toward the LVB, disconnecting it from the dummy load. Then, I connected the now free dummy load to the output of the LVB. I left the dummy load on +17V and +130V, and however connected them to the LVB.

❹ The LVB can be roughly divided in five strips, each for every voltage (+15, -15, -50, +50 and +5V). In this drawing you can see in green all the components related to the -50V regulation. All the other voltages are referred to it.





The wiring to use only the -50V section on the LVB. Note that the +130 is not further regulated and is produced directly by the inverter.

In this way, I had the same situation as before (dummy load on the inverter), except the +17V, +130V and -54V, which, passing thru the LVB, was hopefully going to become -50 (see the drawing above). Out of caution, I removed all the socketed transistor from the +15V section.

Well, what happened when I switched on? As expected, the -50V reached its nominal value… but after 30/40 seconds! Something warming up? No, at all, everything seemed to be right. So, I started the usual battle, analyzing every component. I noted that the 9V reference voltage of the differential amplifier Q1508 was increasing slowly. It shouldn't. The diode CR1510 forbids the reference voltage to reach -9V when the voltage from the sense input is more positive, but removing C1506 or C1511, the behavior was normal. I got mad. Than, I decided to see in the manual how the mainframe put together the -50V with its mating -50V sense input, and I noted that in the rendezvous point, there was a 10 uF capacitor toward ground. I added a similar capacitor to the dummy load and… it worked! I forgot to check with the oscilloscope to see what was happening (probably a self-oscillation), but that allows me to state the first LVB rule:

- in the junction point between the voltage output and sense lines, a 10 uF capacitor (of suitable voltage) must be added.

At that point I was very happy, and continued with the same logic, testing each voltage individually: all of them were correct. Now I was ready for the big leap: all the dummy load on the LVB, expecting a great "I've done it!". Instead, again, click, click, click… My head against the wall.

After other hours, the solution: for a kind of prudence, I used the dummy load resistors half of their recommended values. "if they are enough for the inverter, they will be enough for the LVB", I thought. It is not so. So, the second LVB rule:

- the HEPS requires a good charge on its outputs. Always use the recommended resistance value for the dummy load.

In the middle, the donkey mounted reversed one of the 10 uF capacitor, and that required some extra time, but it is not a HEPS's fault.

Adjustments

Once you have repaired your HEPS, remount it in the mainframe, studying very carefully the path of each cable. Always pay close attention to not disturb the socketed transistors.

Then don't forget the final tuning, not difficult indeed:

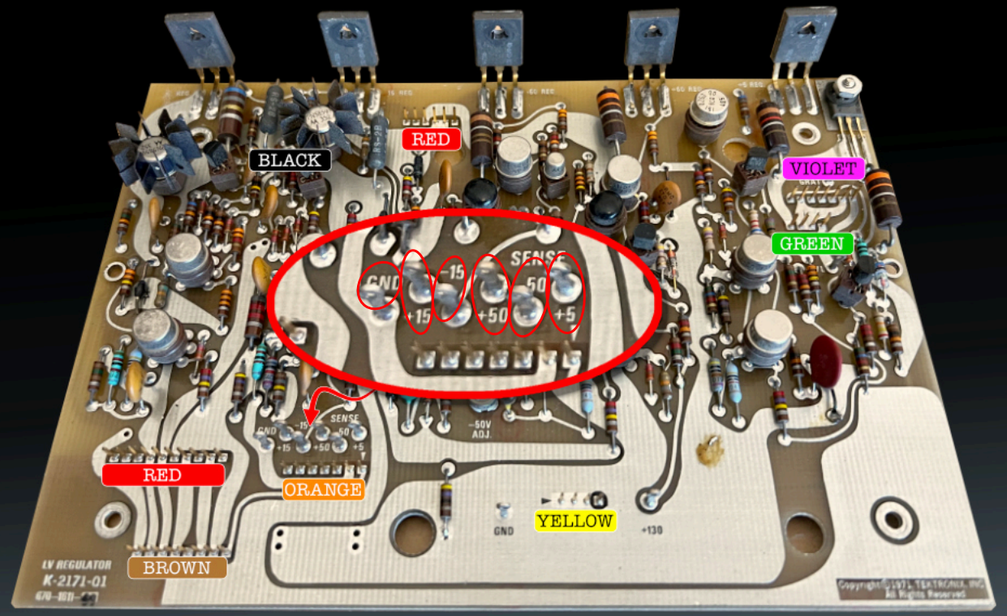
- adjust the voltage at TP1625 (accessible via an hole on the bottom of the HEPS), turning R1293 (it also via another hole on the bottom). The prescribed value is 50 V respect to frame ground for 7844, but it was reduced to 40 V on the subsequent editions of 7904 etc. I set 40V. It is normal that this trimmer has a very wide adjustment range, so it must be turned carefully.
- adjust the voltage at the —50 V test point on respect to the GND test point, acting on R1513 (all the three ate on the LVB). Repeat the adjustment at TP1625, the two are interdependent.

The murder

But, eventually, who was the murder? In reality the murders were two, not one, and both had been arrested independently from the investigations. The first was VR1505 Zener diode on the LVB, that I discovered at the beginning with the coward's tactic. But it was not alone. The other was another Zener diode: VR1297, that the friend Mark Vincent on Tekscopes@group.io had suggested me. All the remaining was generated by crossed mistakes (of the donkey) and by my curiosity to understand the mysteries of the HEPS.



Colors Can Help



The colors can help avoiding errors. In the center detail the LVB test points, that, remember, are on the voltage sense sense lines (the brown connector). They are the real voltages that the mainframe sees. In the detail, the correct interpretation of these test points. The labels can be misleading and more times I have read them in the wrong way.

Conclusions

I hope that all this information can help you in your investigations. The HEPS is really complex, and perhaps much other remained outside this work. It's the second time that I dismount the 7844's HEPS, the first was to recap the CRB, because the readout characters danced visibly.

That work was for me psychologically difficult, for the large number of components to take apart and the possibility to make mistakes, with all those cables and connectors. In the previous pages, you can see the recapped rectifier board, purpose of my first work on the HEPS.

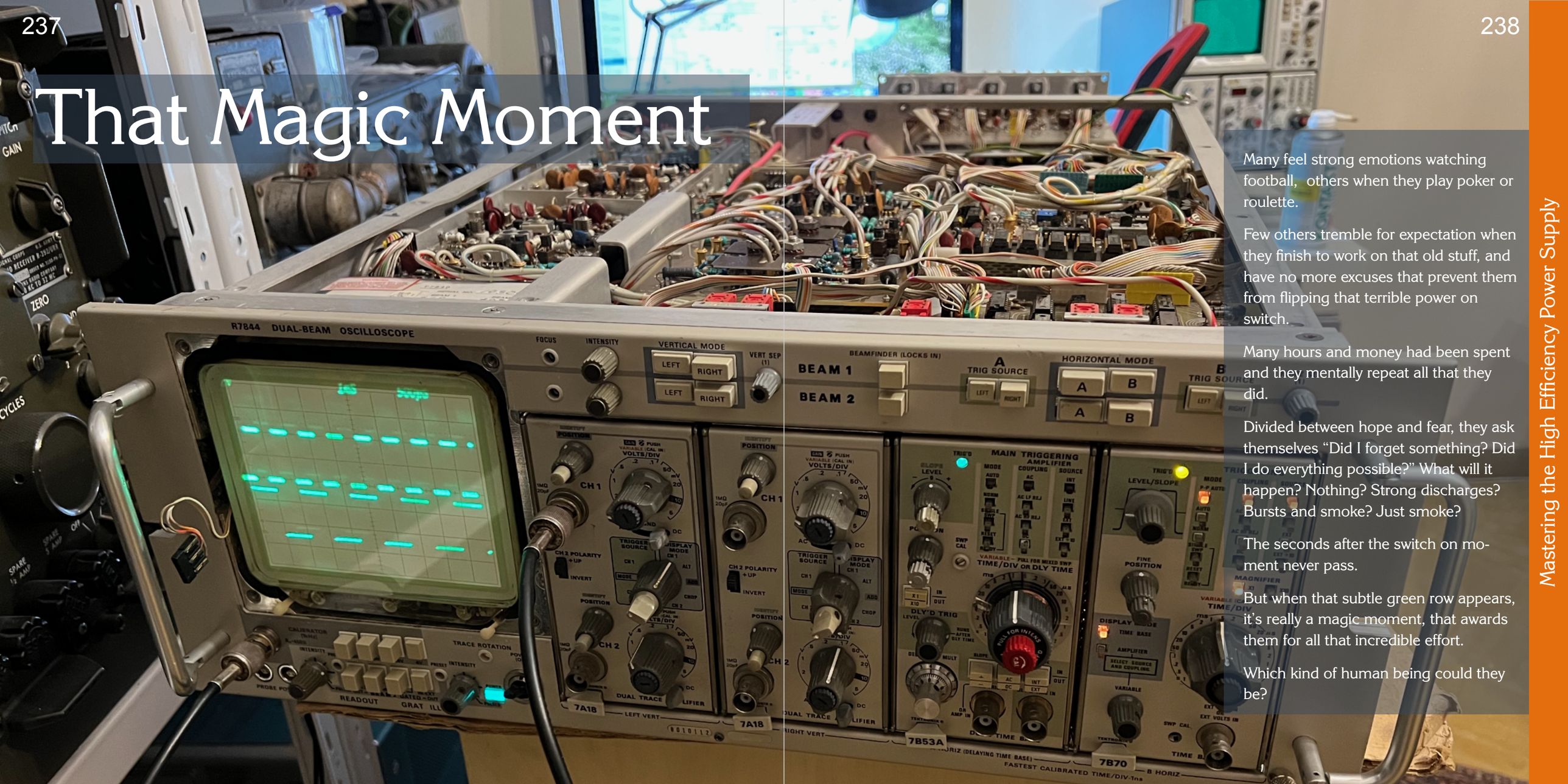
Generally speaking, I am not in favor of indiscriminate dismantling, on the contrary, I am always afraid of combining some troubles and causing damage to my beloved objects. In the past I was not so scary, but when you work in an industry you always take in account to break something and you have a more or less unlimited availability of spare parts. With our old oscilloscopes, a damage could be almost impossible to fix, and anyway you have to stop your work and wait weeks for the spare parts.

This second time I had no choice: the 7844 was absolutely dead and I had little to lose. I must say that the first time I was more scared because I was wandering outside the Pillars of Hercules, in a unknown and insidious sea. This time, after so many tests and investigations, I feel more confident, at least because I better know where and which can be the hazards.

References

- [1] Servicing Tek 7904 Power Supply, Tekscopes March 1971;
- [2] 7904 oscilloscope SN 8260000-up instruction manual, first printing September 1977, revised May 1983, from page 4.8 onward (P/N 070-2390-00)
- [3] 7844/R7844 dual-beam oscilloscope with options service instruction manual, first printing September 1974, revised October 1981 (P/N 070-1676-02)

That Magic Moment



Many feel strong emotions watching football, others when they play poker or roulette.

Few others tremble for expectation when they finish to work on that old stuff, and have no more excuses that prevent them from flipping that terrible power on switch.

Many hours and money had been spent and they mentally repeat all that they did.

Divided between hope and fear, they ask themselves “Did I forget something? Did I do everything possible?” What will it happen? Nothing? Strong discharges? Bursts and smoke? Just smoke?

The seconds after the switch on moment never pass.

But when that subtle green row appears, it’s really a magic moment, that awards them for all that incredible effort.

Which kind of human being could they be?



Subsection: Hi-Voltage Board

Here we analyze in depth the High Voltage Board, the one which produces the high voltages for the CRT's cathode and the Post-Deflection Acceleration.

HV Board Encyclopedia

The opportunity

You will certainly have understood that I have a tendency to get into trouble, but I can't own a beautiful 7904 and leave it dead. In the 7000 Series book, you read about my power-supply-less 7904, that I bought in the first lot of scrap, which led me to the oscilloscope-addiction that you well know. I didn't even want it, but the dealer insisted giving it to me for 20 euros, and I took.

I bought another 7904, declared as dead, to transplant its power supply to my ill 7904, but the dead one resulted to be in splendid form and so the poor Number 1 remained a dead body.

I never could find a spare 7904 power supply, until my friend John Griessen offered me a 7844 power supply for a very reasonable price, and furthermore worked hard to find a way to ship it from the USA to Italy without spending a fortune.

But I didn't notice that the 7844 power supply is not identical, as I thought, to the 7904. Therefore I had to thoroughly study the circuit to understand which modifications could be required. Although my objectives were very specific, most of the descriptions and information reported below are absolutely general and can be useful when restoring / repairing the HEPS.

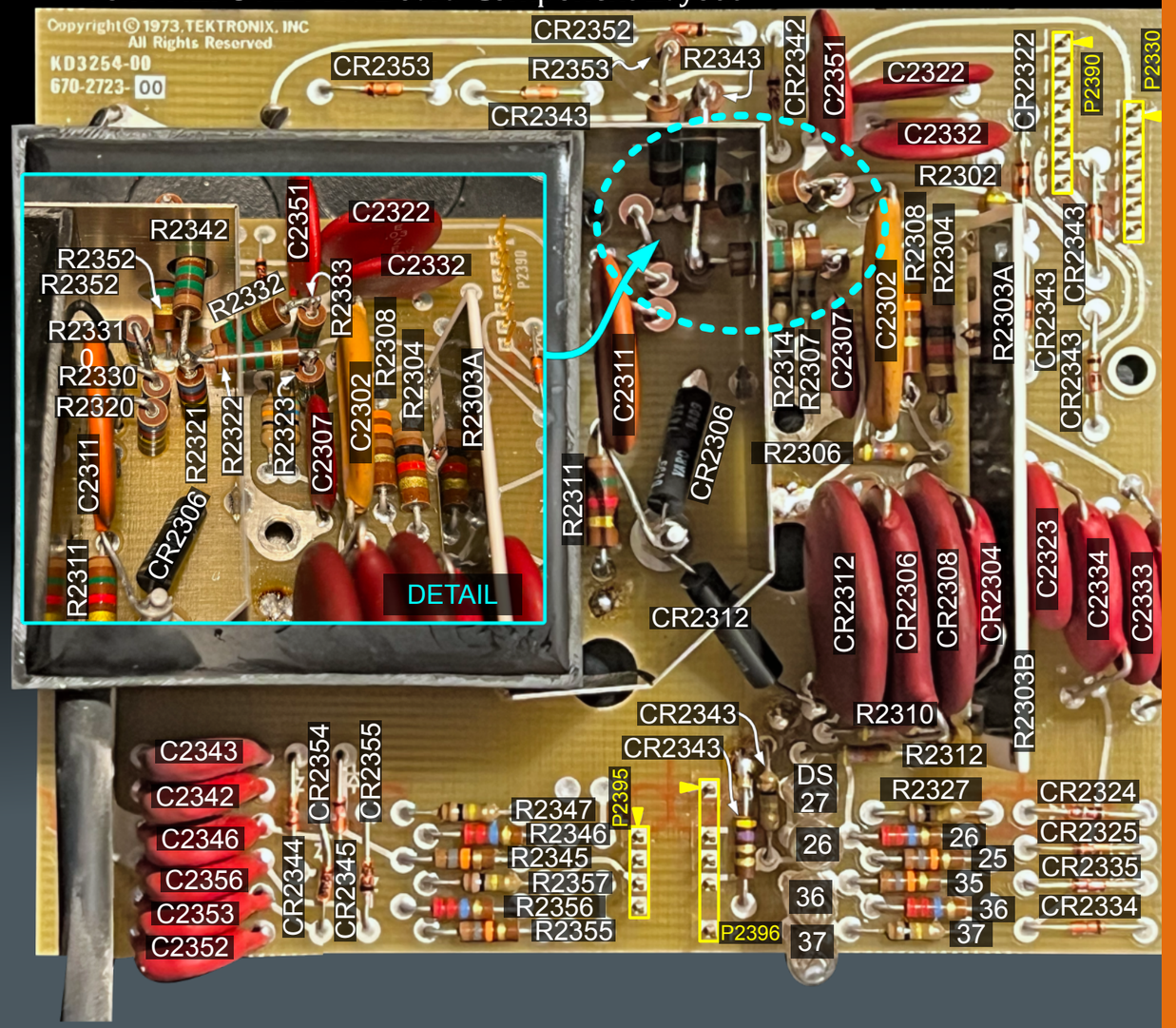
HEPS components

We already saw that a HEPS is composed by four boards:

- A27 Inverter Board;
- A28 Cap Rectifier Board;
- A29 Low Voltage Board;
- A24 High Voltage (HV) board.

For the 7904's HEPS replacement, it seems that only the HV circuit is somewhat different, and thus the deep analysis of the HV Board (named A14 in 7904 and A24 in 7844).

7844 HEPS A24 HV Board Component Layout

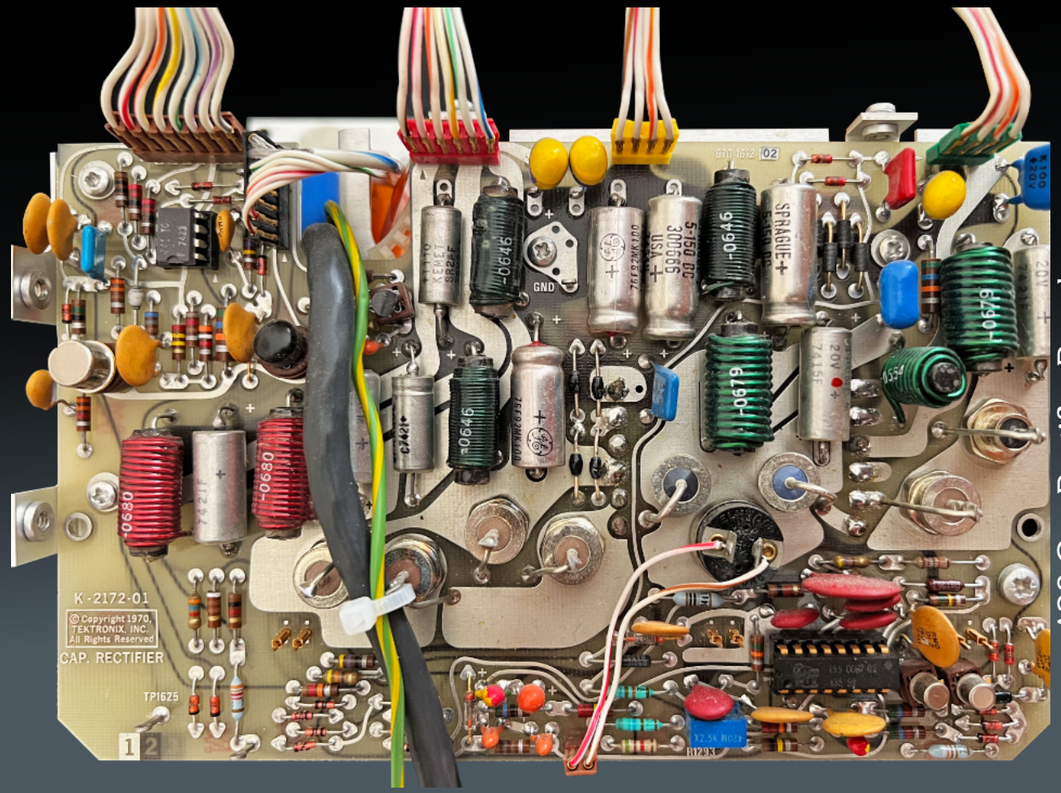


The Low Voltage Board

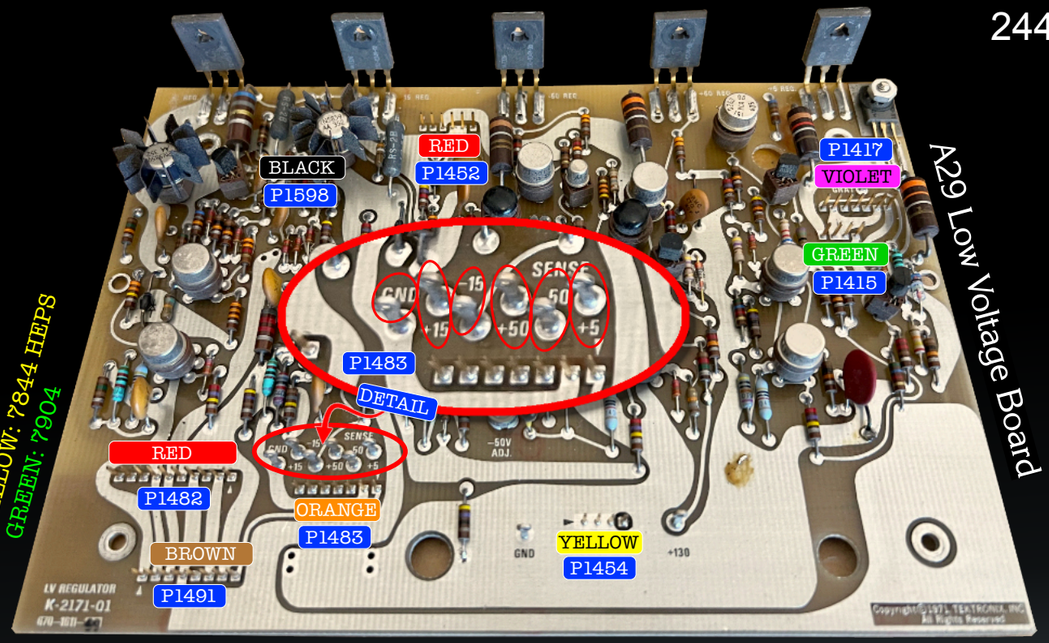
For the LV Board, I compared mainly the connector pins. The quality of the layout images on the manual is poor, and I don't report them here. I update the photo on the right with the connector reference designators and you can see the following differences:

- 7844:P1598 is not present on the 7904. It is used to bring the supply to the 7844 fan, not present in 7904;
- 7844:P1454 is wrongly marked on the 7904 layout, but is identical.

All the connectors connections, checked one by one, resulted to be identical, as shown in the tables on the right. So, I don't expect problems from the LV section.



A28 Cap Rectifier Board



A29 Low Voltage Board

	7844	7904
P1491		
1	+130V	0
2	+15V	0
3	+50V	0
4	-15V	0
5	GND	0
6	LINE TRIG	0
7	-50	0
8	BEAM I SENS	0
P1482		
1	+130V	0
2	LINE TRIG	0
3	+5V	0
4	-15V	0
5	-50V	0
6	+50	0
7	+15V	0
8	GND	0
9	GND	0
10	L COM	0

	7844	7904
P1483		
1	BEAM I SENS	
2	GND	0
3	+5V	0
4	-50V	0
5	+50V	0
6	-15V	0
7	+15V	0
P1454		
1	GND	0
2	GND	0
3	GND	0
4	+130V	0
P1415		
1	+7V	0
2	LIGHTS COM	0
3	LIGHTS COM	0
4	+5V LIGHTS	0

	7844	7904
P1417		
1	+15V	0
2	LIGHTS COM	0
3	+5V LIGHTS	0
4	+5V LIGHTS	0
5	GRAT SUPPLY	0
6	LIGHTS COM	0
7	GRAT POT	0
P1452		
1	-17V	0
2	-17V	0
3	+54V	0
4	+17V	0
5	+17V	0
6	-54V	0

The High Voltage Board

Here the devil stays. For more reasons; among them, is that you are dealing with high voltages, and that the HEPS is rather complex and tedious to tear off. Even to fix a simple error, you must work a lot.

Let's analyze the functions of the 7844 A24 HV Board (block diagram on the opposite page):

- host the **Voltage Multipliers** and the **HV Regulator** which produce the stabilized -2.96 kV and the 21 kV voltages. They are identical between 7844 and 7904, which even use the same reference designators (see the schematics on the previous page, don't care the "x14" inscription in the 7844 schematic diagram, it's a just a typo). Both have the same connectors toward the HEPS A28 Capacitor Rectifier Board (P2330 on HEPS, P1630 on 7904).
- host the **DC Restorer** circuit which produces the **CRT Control Grid** bias, i.e., the trace brightness signal. Its input is not the INTENSITY front panel control as you could think, but it comes from the Z-Axis circuit because it embeds the blanking signal for the retrace. We talked a lot about the interesting DC Restorer circuit in the 7844 section.
- host the **DC Restorer** circuit which produces the **CRT Focus Grid** bias; this input comes from the Autofocus Amplifier, which is hosted on the A16 Z-Axis Board in the 7904 and on the A23 CRT Board in the 7844.

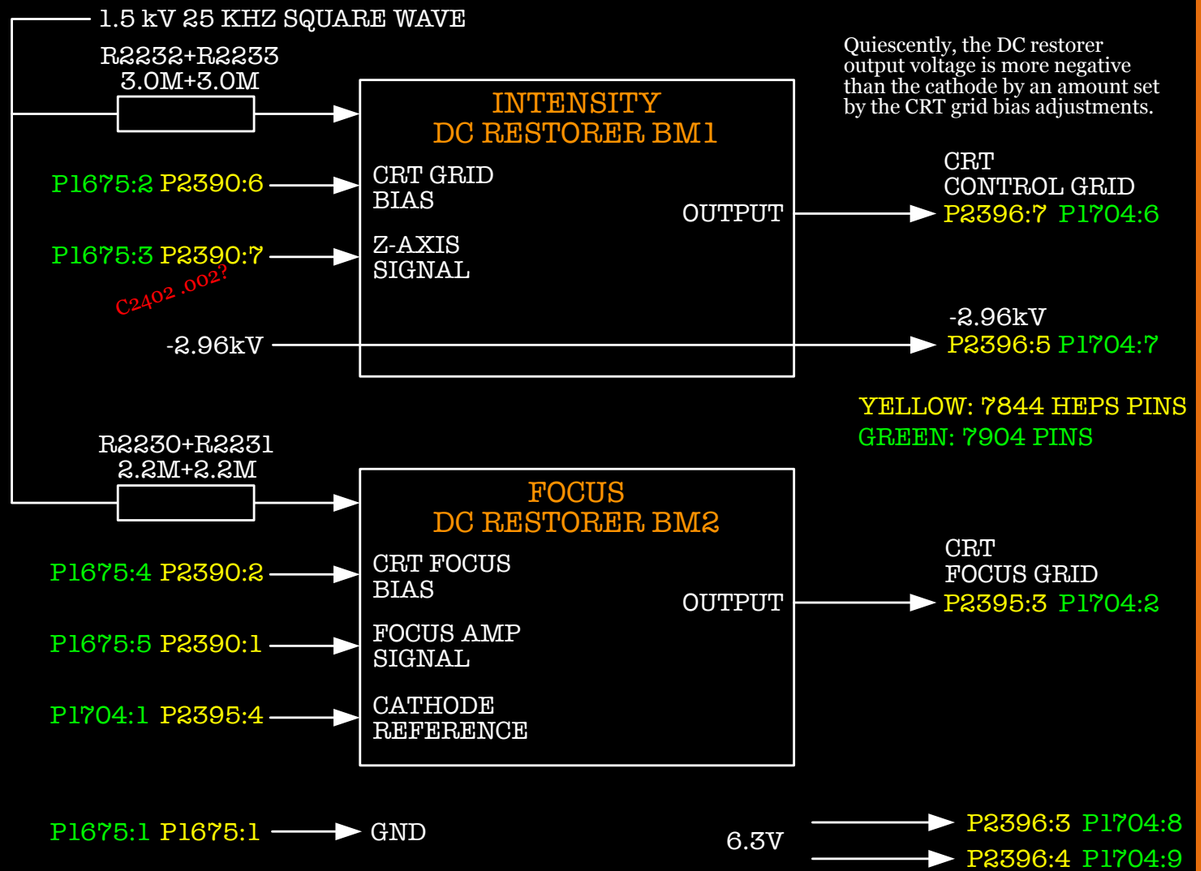
Differences

After a long study, I understood what follows:

- the 7904, who knows for what reason, uses an additional board A15 Auto Focus Board for the focus DC restorer;
- later, when designed the 7844 HV board, they discovered that it could host not only that board but also the two DC Restorers for the CRT's second beam.

So, I was lucky: I didn't need the A15 Auto Focus Board, which I don't have, because the same circuitry is already contained in the 7844 A24 HV Board.

I decided to use the Beam 1 Intensity DC Restorer and the Beam 2 Focus DC Restorer, because in this way the modification is easier (the two are both supplied by the R2330 and R2331 resistors).



Connections to the 7904

The mission is thus to define the new wiring, to connect the HV Board to the 7904 A16 Z-Axis Board (opposite page), precisely to P1675 and P1704 connectors.

Note that the two black connectors P1710 and P1720 are mounted on the back of the 7904 Z-axis board and go directly to CRT. This is not related with the discussion but I lost a lot of time looking for them, and it might be useful to know.

I'll spare you all my boring ruminations and give you the resulting interconnection tables, which describe the required cables, either from the 7904 point of view, either from the HEPS.

7904	7844 HVB	Signal
P1675:1	?	GND
P1675:2	P2390:6	CRT GRID BIAS BM1
P1675:3	P2390:7	Z-AXIS SIG BM1
P1675:4	P2390:2	+130V
P1675:5	P2390:1	AUTO FOCUS BM2
P1704:1	P2395:4	FOCUS PRESET BM2
P1704:2	P2395:3	FOCUS GRID BM2
P1704:3		Not used
P1704:4		Not used
P1704:5		Not used
P1704:6	P2396:7	CONTROL GRID BM1
P1704:7	P2396:5	-2960V (CATHODE)
P1704:8	P2396:3	6.3V pull down to -2,960V
P1704:9	P2696:4	6.3V

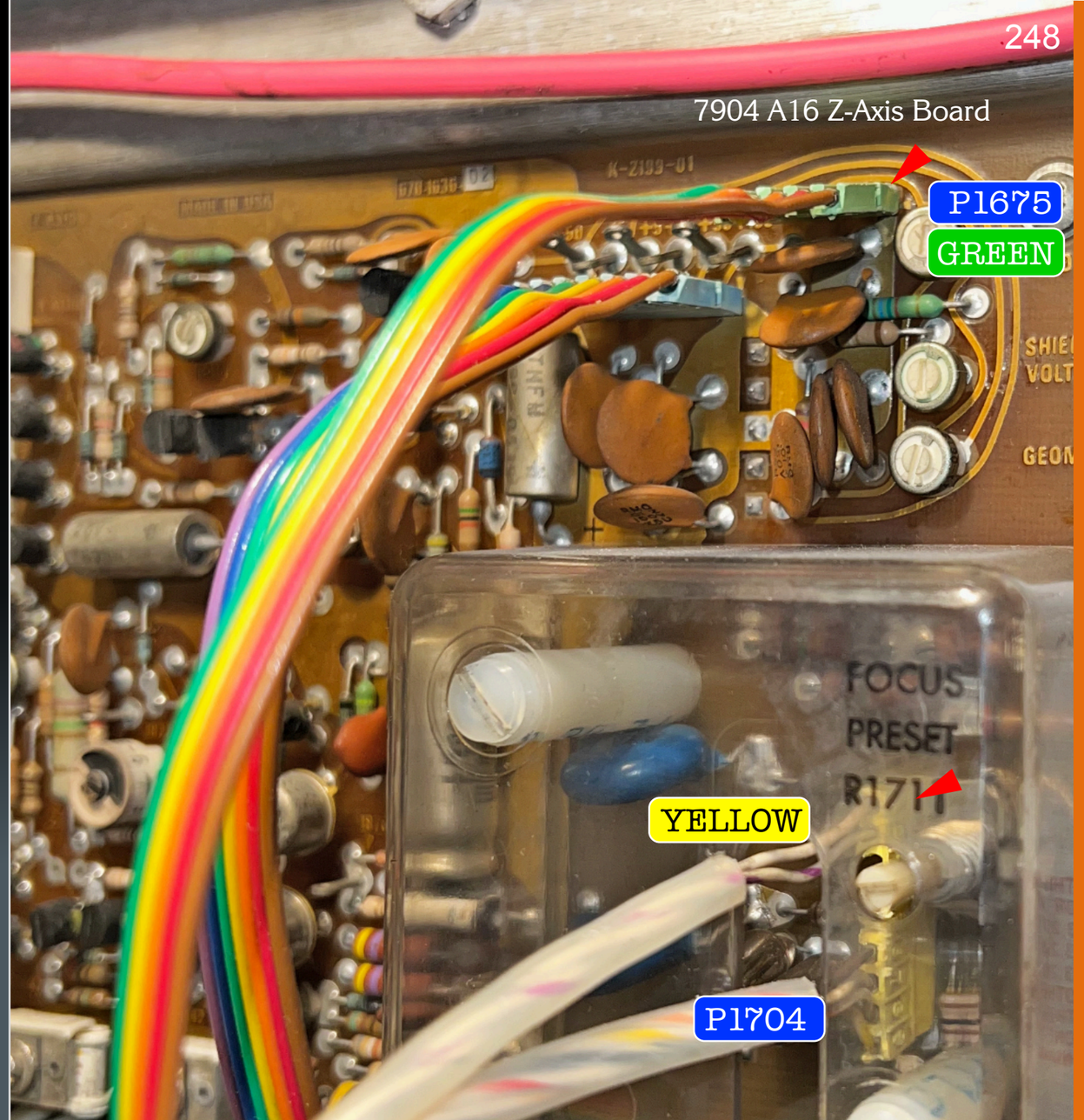
7844 HVB	7904	Signal
P2390:1	P1675:5	AUTO FOCUS BM2
P2390:2	P1675:4	+130V
P2390:3		AUTO FOCUS BM1
P2390:4		CRT GRID BIAS BM2
P2390:5		Z-AXIS BM2
P2390:6	P1675:2	CRT GRID BIAS BM1
P2390:7	P1675:3	Z-AXIS BM1
P2395:1		FOCUS GRID BM1
P2395:2		FOCUS PRESET BM1
P2395:3	P1704:2	FOCUS GRID BM2
P2395:4	P1704:1	FOCUS PRESET BM2
P2396:1		CONTROL GRID BM2
P2396:2	NC	
P2396:3	P1704:8	6.3V pull down to -2,960V
P2396:4	P1704:9	6.3V
P2396:5	P1704:7	-2960V (CATHODE)
P2396:6	NC	
P2396:7	P1704:6	CONTROL GRID BM1

Differences

Besides the wiring, I observed only few differences, easy to fix:

- the resistors in series with the 25 kHz 1.5 kV square wave must be changed (see below);
- capacitor C2402 (0.001 uF) is missing; I did not add it.

Photo on the right: the 7904 Z-Axis board.



Modifications

The modifications for using the 7844 HEPS in the 7904 are small: remove R2320, R2321, R2322, R2323, R2343, and replace the following resistors, to make them in green the 79049:

- R2330 (620K) + R2331 (620K) in series with BM1 Intensity e BM2 Focus [1.3M + 1.3M]: 2,586
- Beam 1 Intensity: it has in series R2332 (1.5M) + R2333 (1.5M) [3.0M + 3.0M]; about 6,050
- Beam 2 Focus: it has in series R2352 (1.5M) + R2353 (1.5M) [2.2M + 2.2M].

The Tek's choice of using two resistors in series is probably due to voltage requirements; in this way the tension at the resistor's terminals is a half. I obtained the required value by selecting proper resistors even if not equal to each other (respectively 1+1.5, 2.7+3.3, 2.2+2.2).

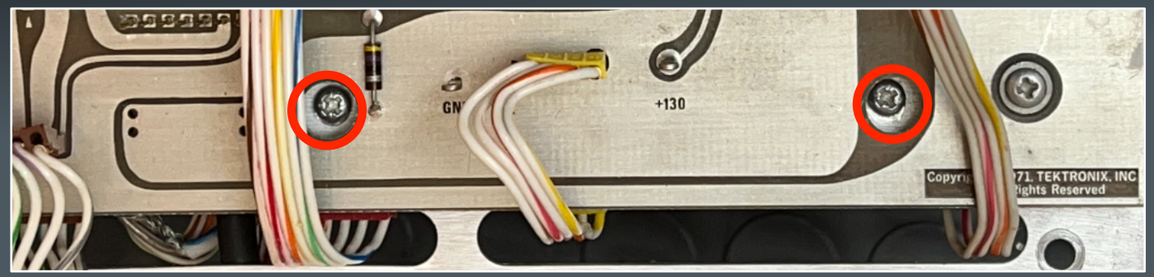
Physical connections

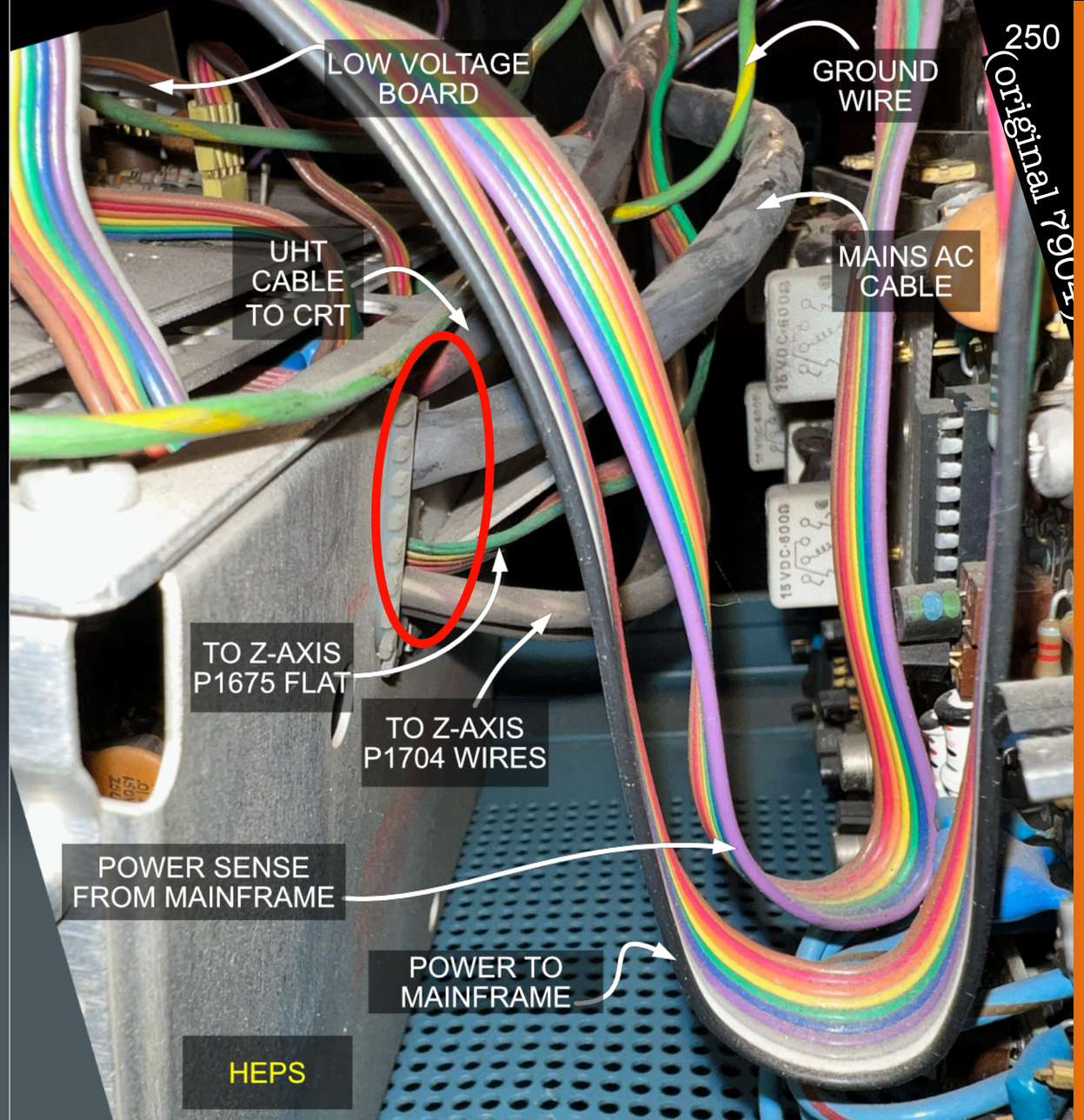
All that above is theory. Now, it's time to see how to practically implement the modifications (or the repair, according your needs). From the true 7904 HEPS two group of wires come out (see the ugly but useful photo on the right page, taken from the good 7904):

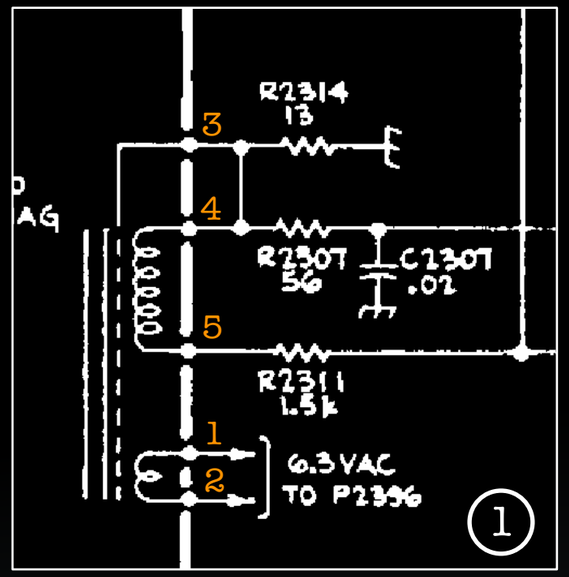
- the upper: the mains AC power supply (thick black), the ground wire and the UHV cable for the post-acceleration (thick red);
- the lower:
  - two high insulation cables going to P1704 on the Z-axis board (yellow connector)
  - a five-wire flat cable going to P1675 (green connector).

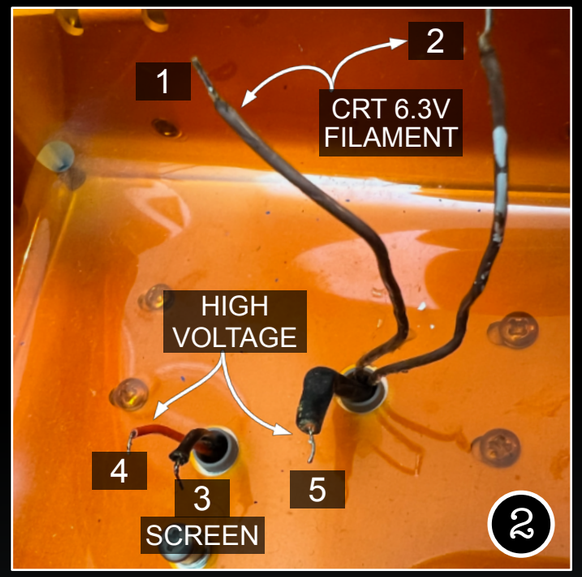
No other cable comes out the 7904 HEPS.

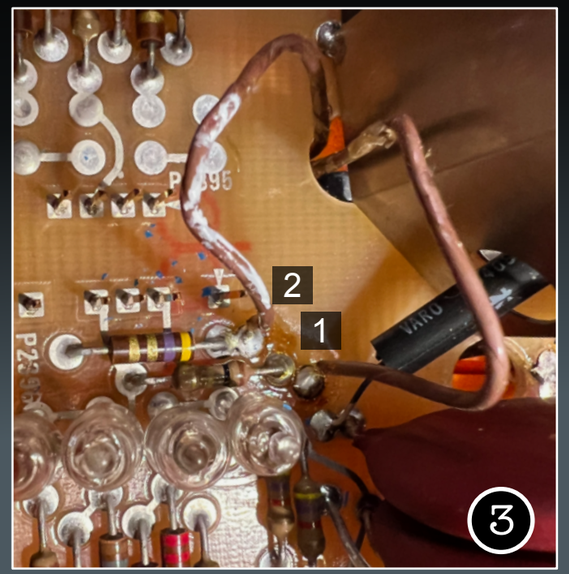
❶ The screws used to release the LV Board.
❷ The cables coming out the HEPS in a good 7904.

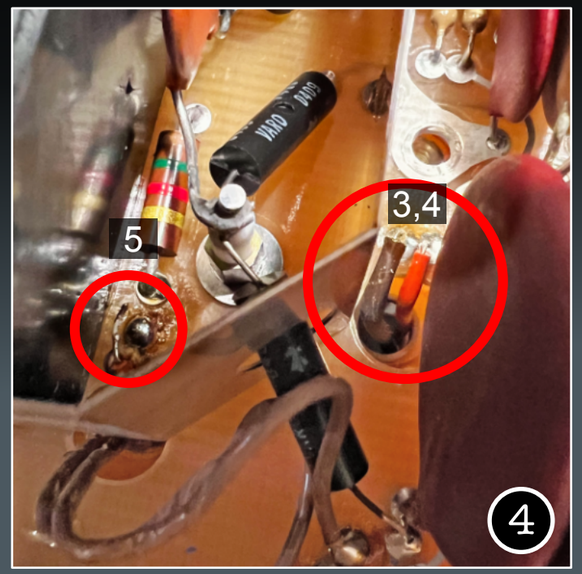












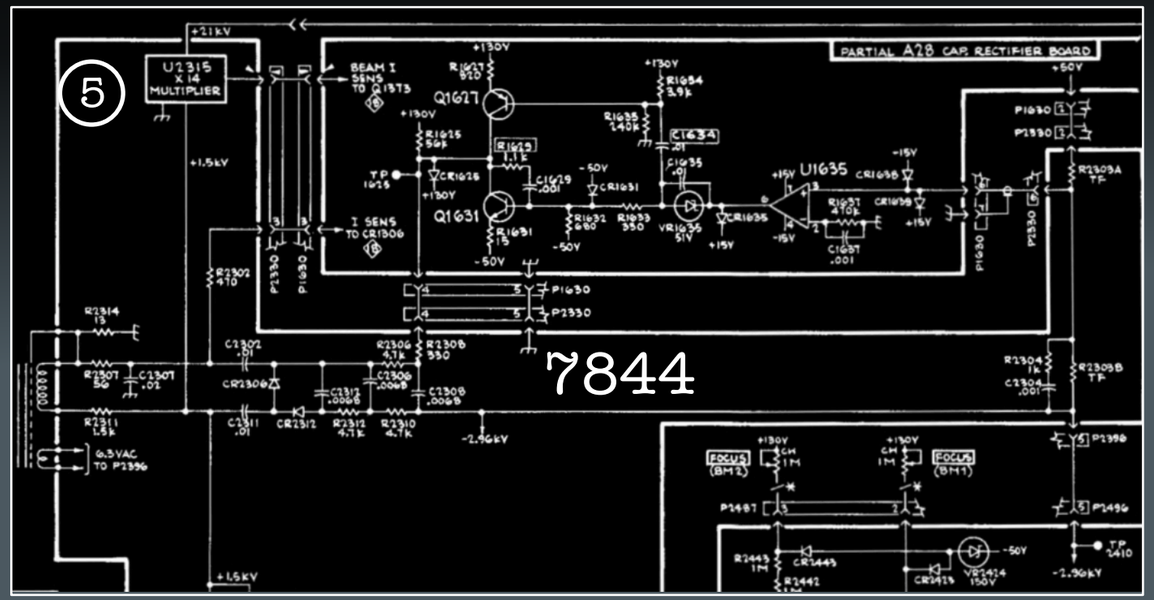
Accessing the HV Board

To reach the HVB you don't need to disassemble all the HEPS, but "only":

- remove the HEPS from the oscilloscope;
- remove the lower/rear aluminum cover (four screws)
- remove the LV Board; you can leave it mounted on its metal frame, just remove the two small screws circled in red here below and the five ones which block the power transistors to the main panel.

Now you can reach the HVB, but I was not able operate on it without removing it from its place, so I will describe this job as well.

❶ T1310 HEPS transformer includes also the HV secondaries.
❷ T1310 transformer's connections, coming out in the High Voltage Board compartment.
❸ T1310 filament connections.
❹ T1310 High Voltage and screen connections.
❺ 7844 high voltage stabilizer circuit. The 7904 is almost identical.



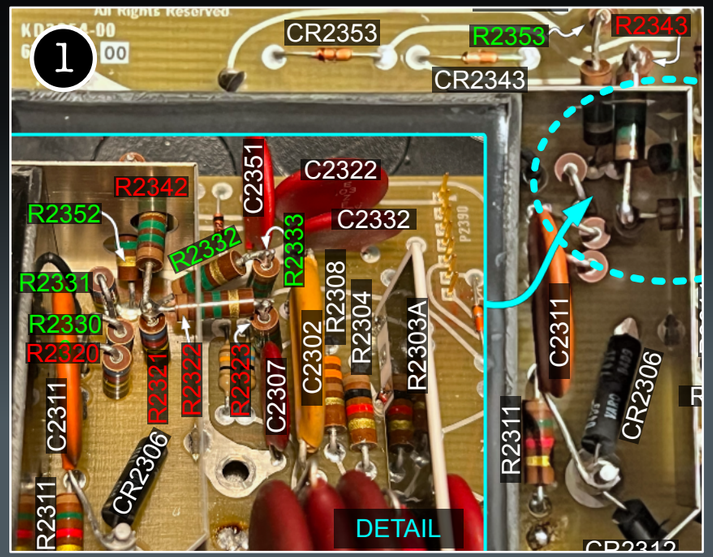
Removing the HV Board

Removing the HVB is not very easy, but it can be done with the help of the many drawings here reported, with patience and care. The problem is that it is fixed with only one screw, but it is linked by the connections to the T1310 transformer below by mean of five wires (see photos on the opposite page). The wires are impossible to be wrongly connected. As you can see, I marked in white one of the two brown wires, but it is not necessary. They are the supply to the CRT's filament and can be swapped.

I suggest that you suck up the solder from the PCB pads before remounting, After soldering, I cleaned as much as I could the board from the residues, thinking that they could create discharges with the HT.

Modification map

Here below the map of the modification to the 7844 HVB to use it with the 7904. In red the resistors to be removed, in green those which require to be replaced with different values.

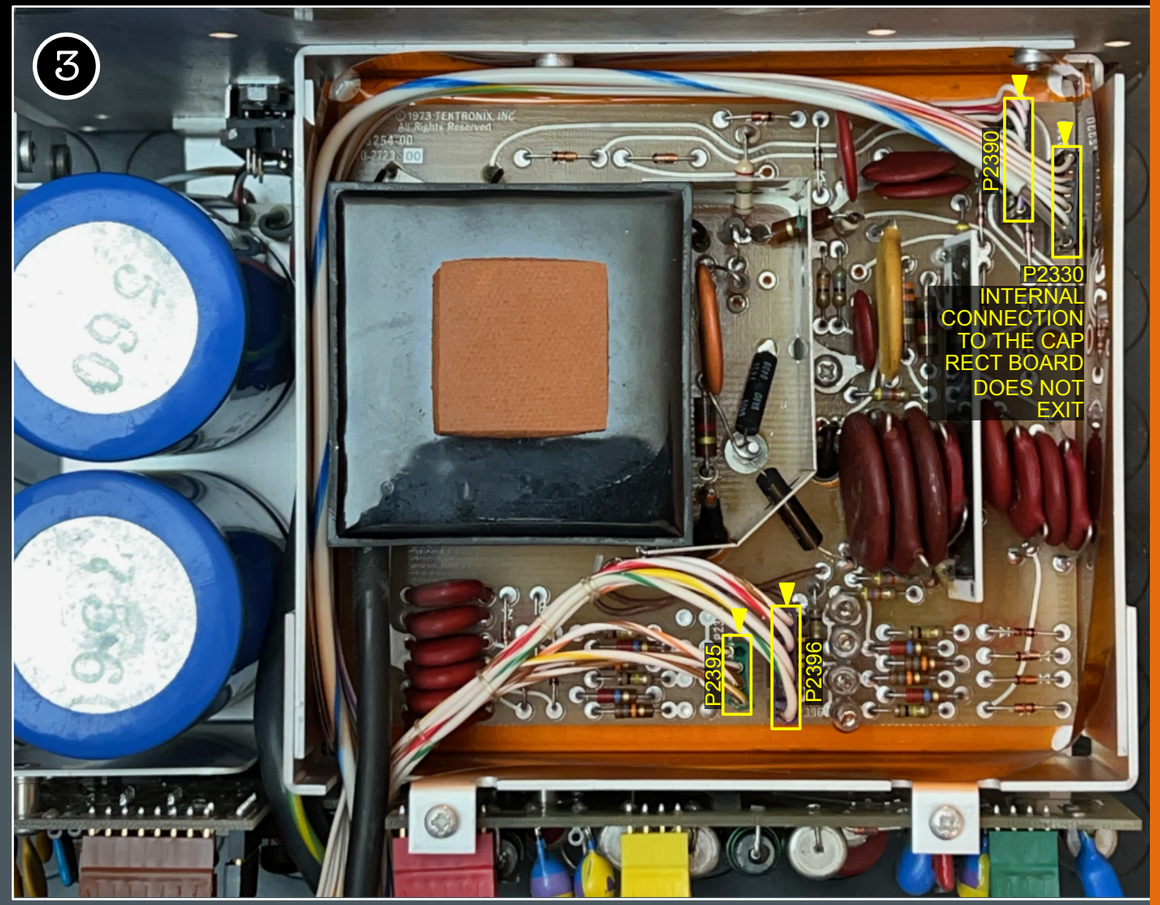




Drawings and schematics

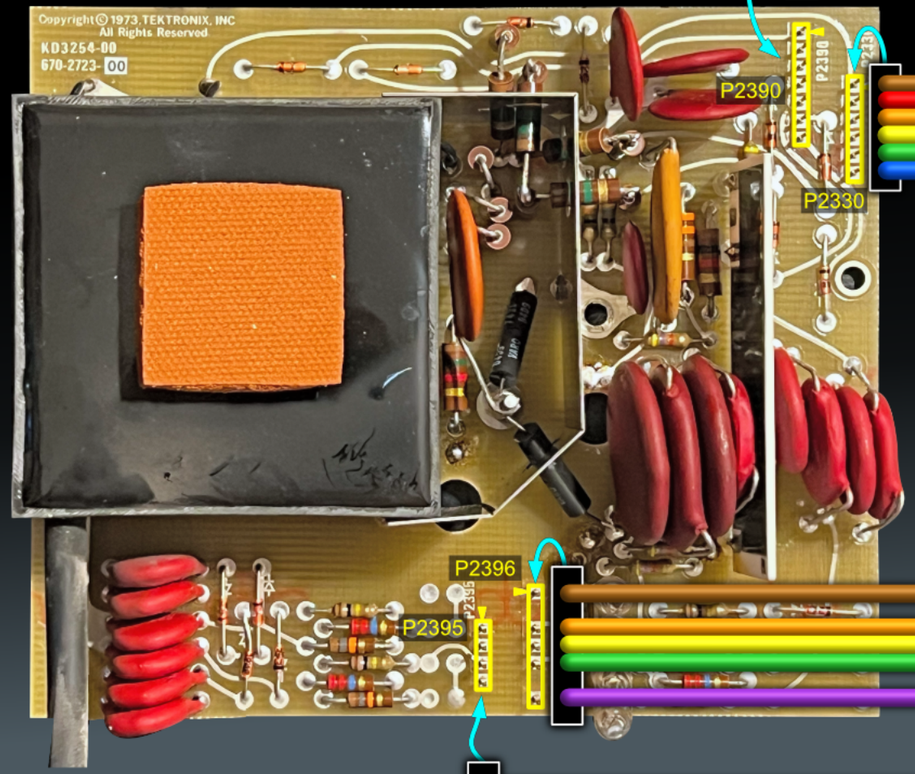
In the following pages you can find many drawings that should make clearer the situation. I hope that they can be useful not only for this improbable transplant, but for everybody who is going to fix a 7904 or a 7844.

❶ The modification for using the 7844 in the 7904. In red the resistors to be removed, in green those to be changed in value.
❷ The HV board after the modification.
❸ The HV Board replaced in its seat. This photo shows also how the interconnecting cables run to reach the exit slot.



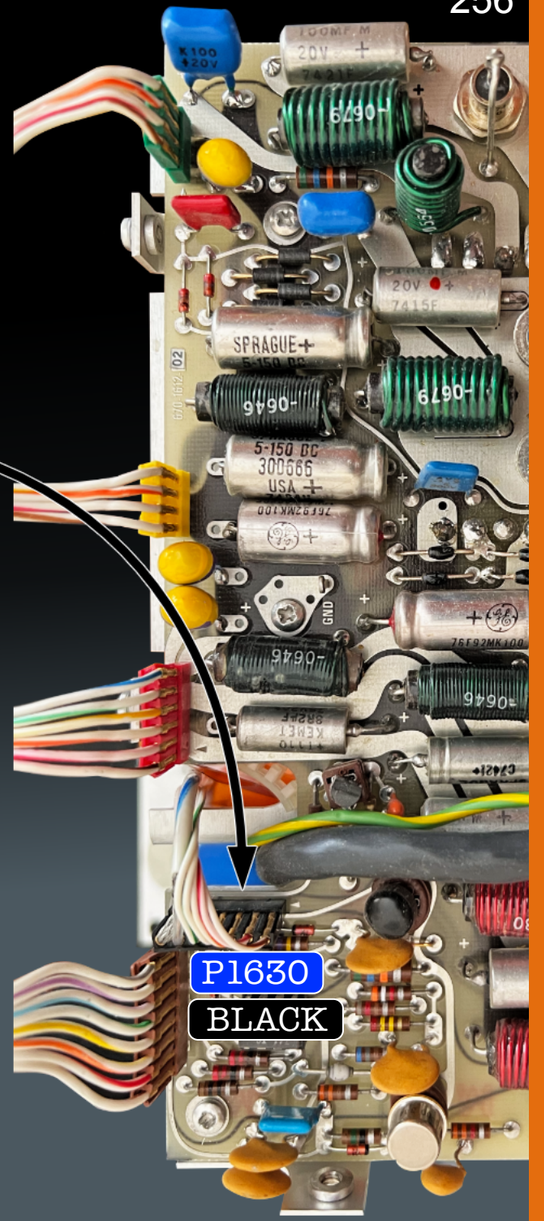
Connect to the LV Board

7844 HEPS A24 HV Board



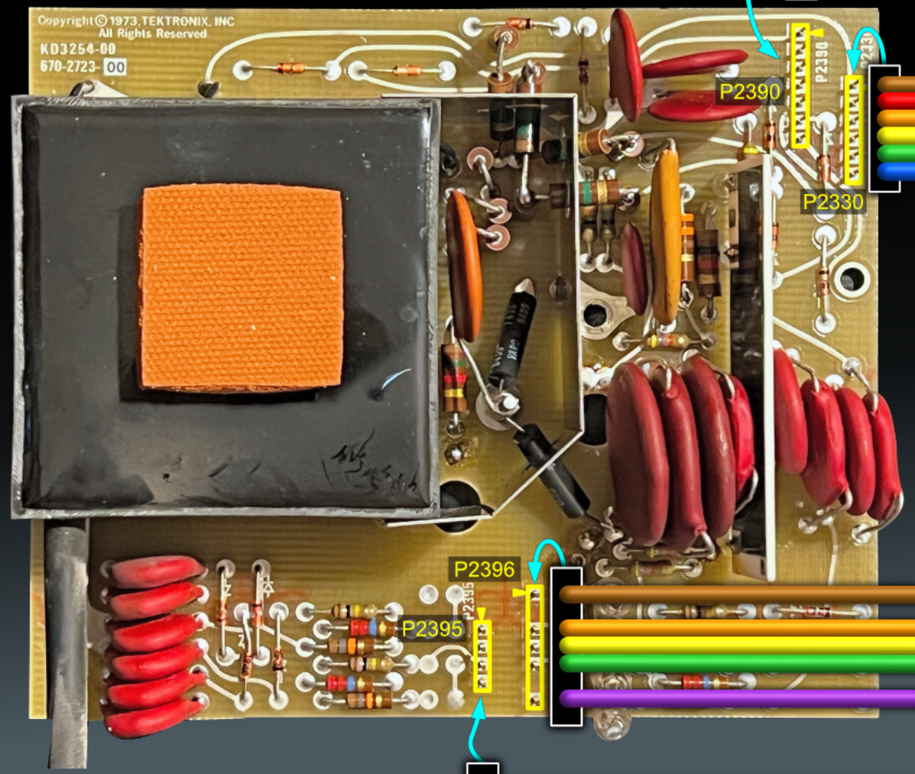
7844 HVB	CAP_RECT	Signal
P2330:1	P1630:1	BEAM I-SENS
P2330:2	P1630:2	+130V
P2330:3	P1630:3	I-SENS
P2330:4	P1630:4	V-CONTR OUT
P2330:5	P1630:5	GND
P2330:6	P1630:6	OPAMP IN
P2330:7*	P1630:7	GND
		*Really does not exist

Black



Connect to the Z-Axis

7844 HEPS A24 HV Board



7844 HVB	7904	Signal
P2390:1	P1675:5	AUTO FOCUS BM2
P2390:2	P1675:4	+130V
P2390:3		
P2390:4		
P2390:5		
P2390:6	P1675:2	CRT GRID BIAS BM1
P2390:7	P1675:3	Z-AXIS BM1

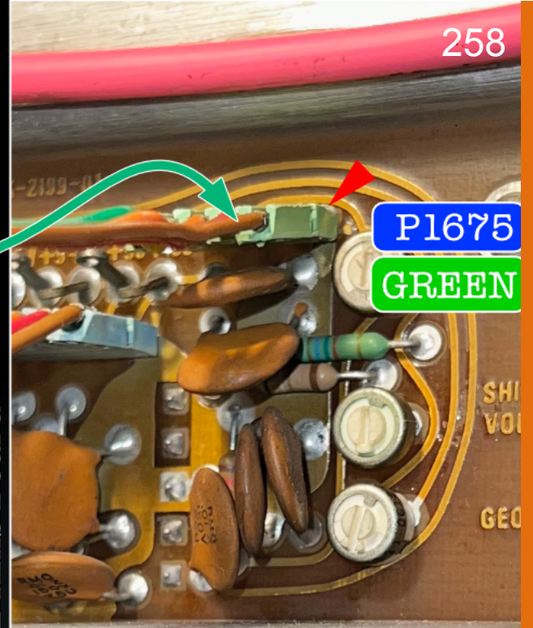
7844 HVB	7904	Note
P2396:1		
P2396:2		
P2396:3	P1704:8	6.3V pull down to -2,960V
P2396:4	P1704:9	6.3V
P2396:5	P1704:7	-2960V (CATHODE)
P2396:6		
P2396:7	P1704:6	CONTROL GRID BM1

7844 HVB	7904	Note
P2395:1		FOCUS GRID BM1
P2395:2		FOCUS PRESET BM1
P2395:3	P1704:2	FOCUS GRID BM2
P2395:4	P1704:1	FOCUS PRESET BM2

Green

Yellow

7904 A16 Z-Axis Board







1 7904 A16 Z-Axis Board

HEPS to 7904 Wires

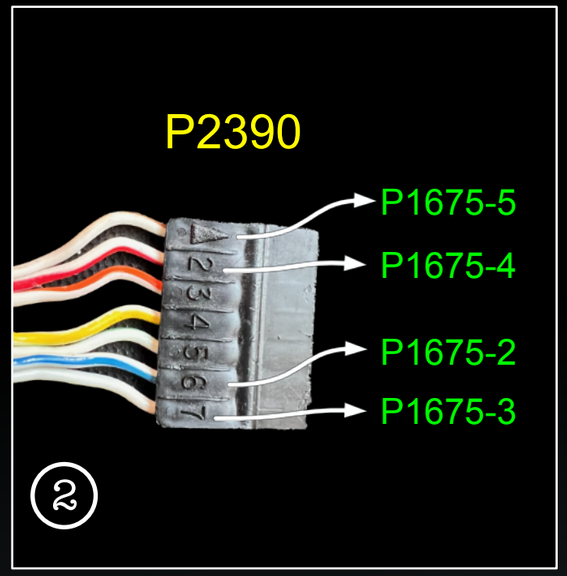
To connect the HEPS to the 7904 (Z-Axis board) we use the original 7844 HEPS cables, changing only the terminating connectors as shown here.

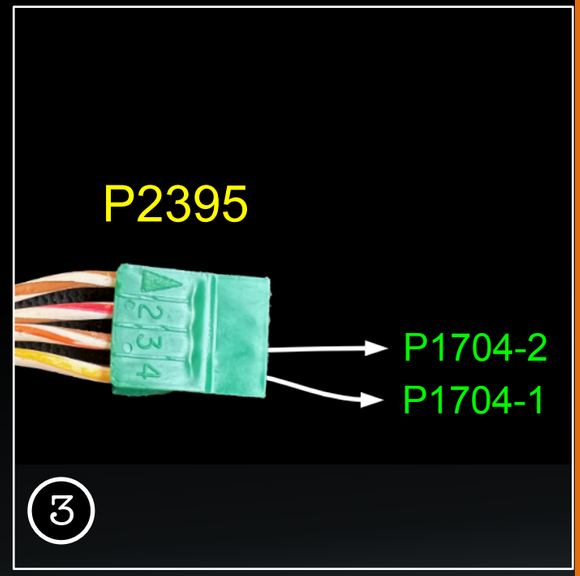
Phantom pins

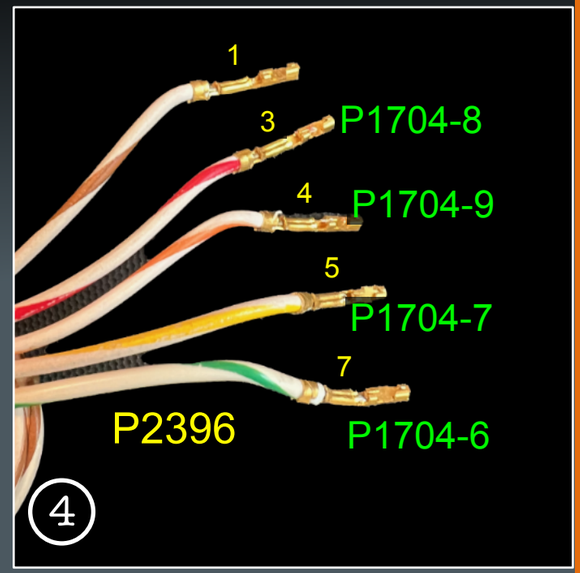
Observe that both P2395 (HV Board) and P1704 (7904 Z-Axis) use “phantom pins”, i.e., some pins not really present in the connector but counted in the pin assignment (this is not a general rule; in other Tektronix products they are not counted).

Despite this, the colors assignment in P2395 cable ignore those phantom pins; thus:

- 1 = brown;
- 2 is not present;
- 3 = red;
- 4 = orange;
- 5 = yellow;
- 6 is not present;
- 7 0 green.







❶ The Z-Axis board of the 7904. Note P1704 pin numbering.

❷ How to connect P2390 from the HV Board to 7904 P1675.

❸ How to connect P2395 from the HV Board to 7904 P1704.

❹ How to connect P2395 from the HV Board to 7904 P1704. Note that the wires color encoding ignores the phantom pins (see the text).

Theory and Practice

I arrived at this point and all I described until now is still to be tested. I have no idea if the transplanted 7844 HEPS can work and if the old 7904 can be resurrected. I don't even know if the old 7904 mainframe can be saved. Is the CRT good? Which strange fault might stay hidden in the dark?

In addition, I am a big wimp. It should be crazy having arrived at this point and destroy something for the hurry. So I decide to check all again, and the best way to do it is to create a more complete documentation.

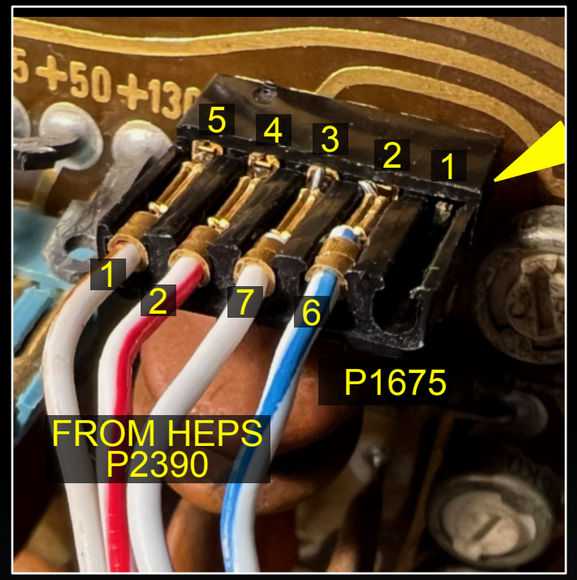
Let's review the signals

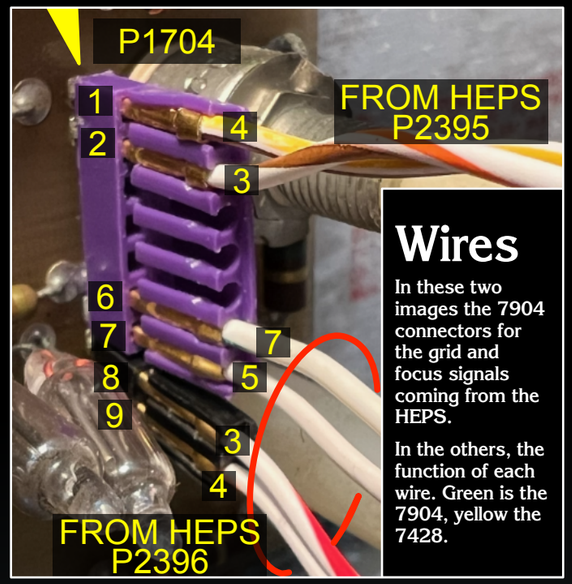
Let's start by compiling the table below and revising the purpose of each signal. As used, green is the color of the 7904, yellow the one of the 7844 HEPS. The signals in gray are static signals, like fixed or trimmer adjustable voltages In this way, it's more evident that the main function of this board is to translate the voltages from the amplifiers to CRT's grids. The column COLOR list the main identifying color of the connecting wires.

FROM	DIR	COLOR	TO	Signal	Description
P1675:4	→	RED	P2390:2	+130V	Directly from the power supply
P1675:2	→	BLUE	P2390:6	CRT GRID BIAS BM1	Output from the CRT GRID trimmer between +130V and ground.
P1704:1	→	YELLOW	P2395:4	FOCUS PRESET BM2	Output from the FOCUS PRESET trimmer
P1675:3	→	VIOLET	P2390:7	Z-AXIS BM1	Output from the Z-Axis amplifier
P1675:5	→	BROWN	P2390:1	AUTO FOCUS BM2	Output from the autofocus amplifier
P2396:3	→	BROWN	P1704:8	6.3V (pull down to -2,960V)	CRT filament power supply
P2396:4	→	ORANGE	P1704:9	6.3V	CRT filament power supply
P2396:5	→	RED	P1704:7	-2960V (CATHODE)	Fixed voltage
P2396:7	→	GREEN	P1704:6	CONTROL GRID BM1	CRT control grid
P2395:3	→	BROWN	P1704:2	FOCUS GRID BM2	CRT Focus grid

The 7844 High Efficiency Power Supply going to be implanted in the 7904



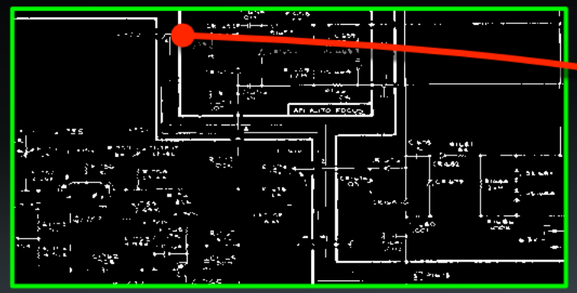


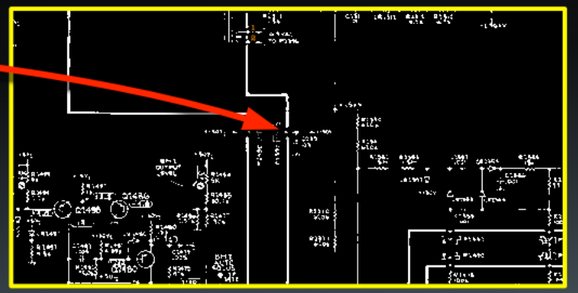


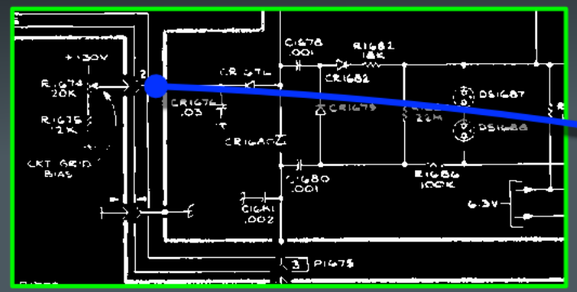
Wires

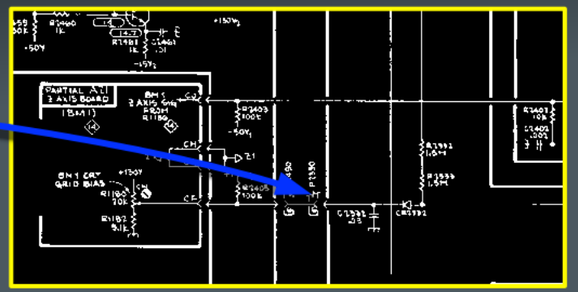
In these two images the 7904 connectors for the grid and focus signals coming from the HEPS.

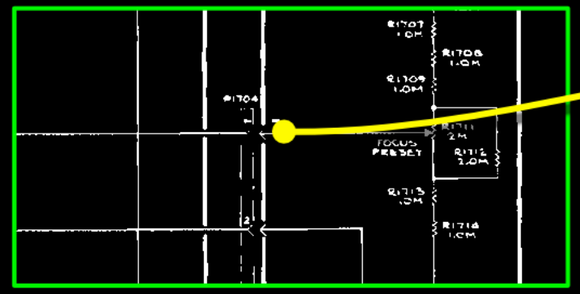
In the others, the function of each wire. Green is the 7904, yellow the 7428.

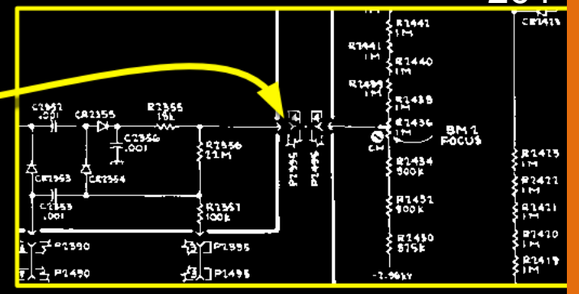


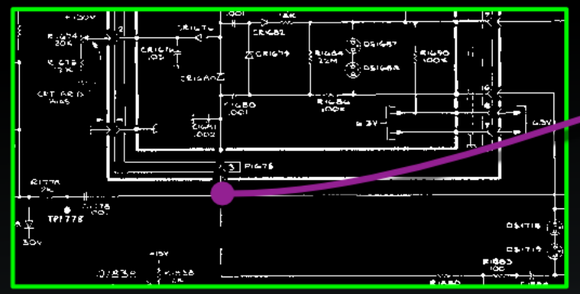


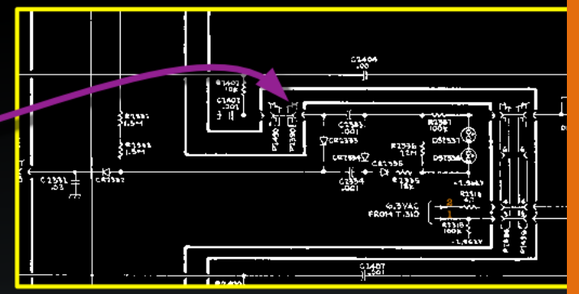


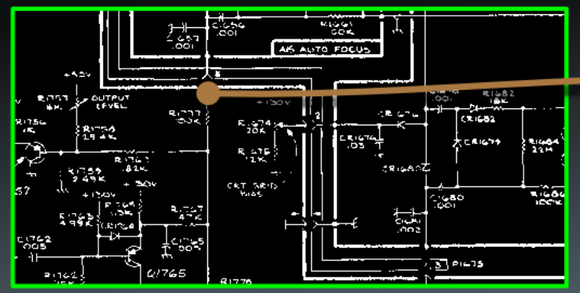


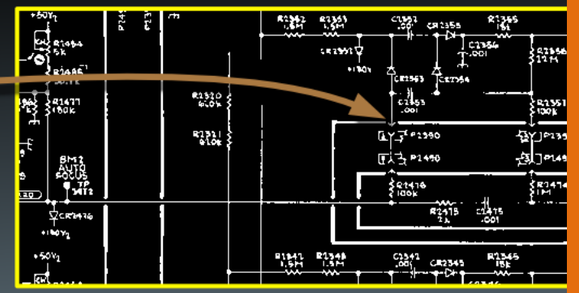


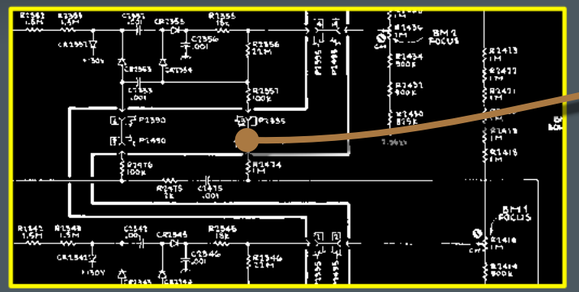


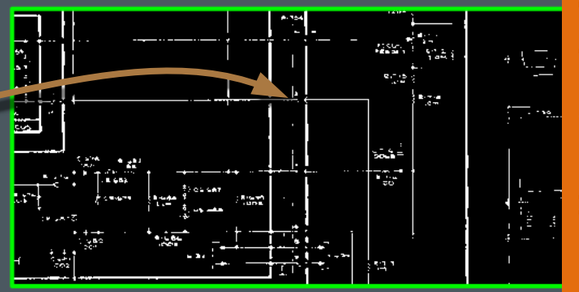


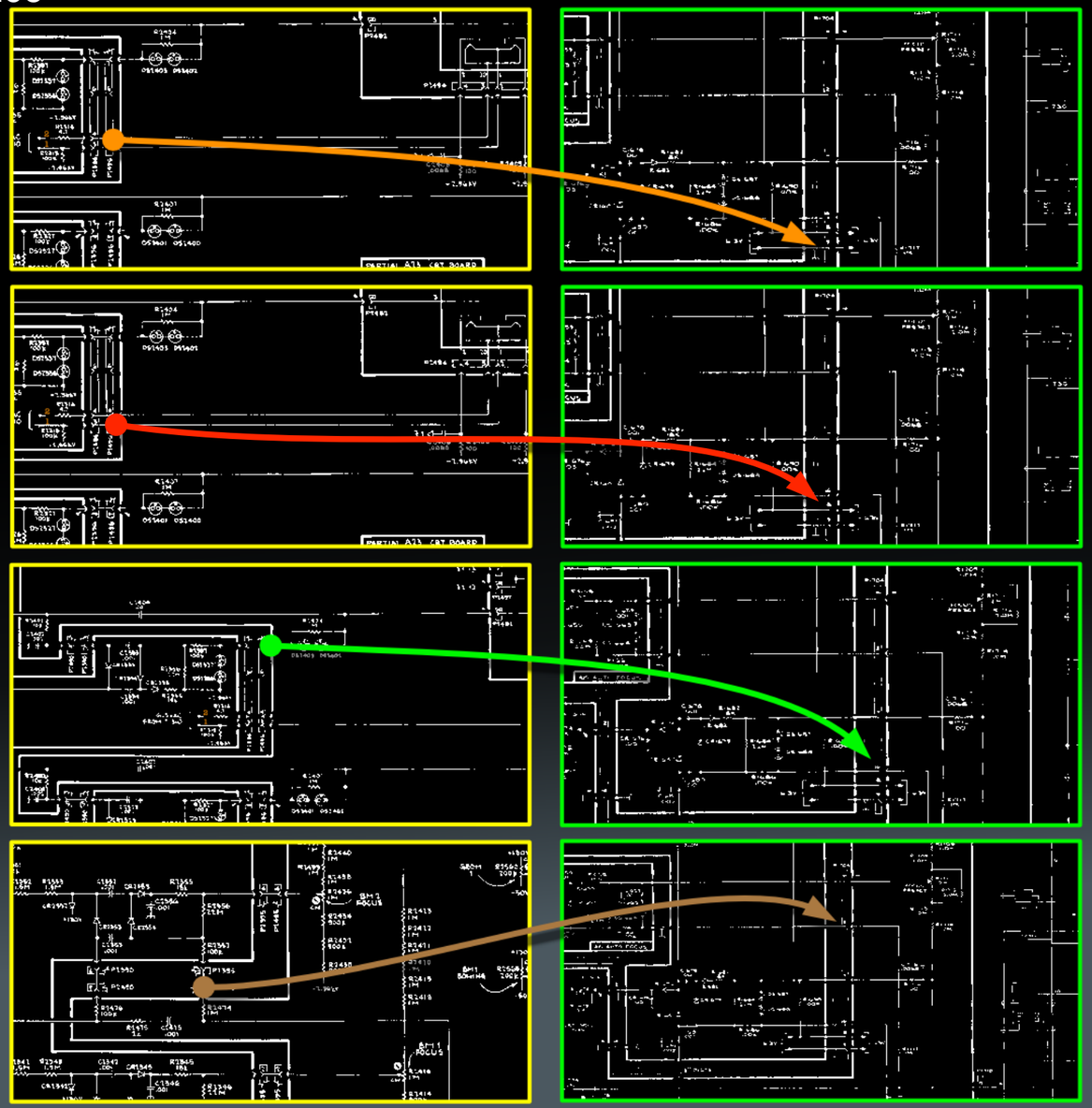


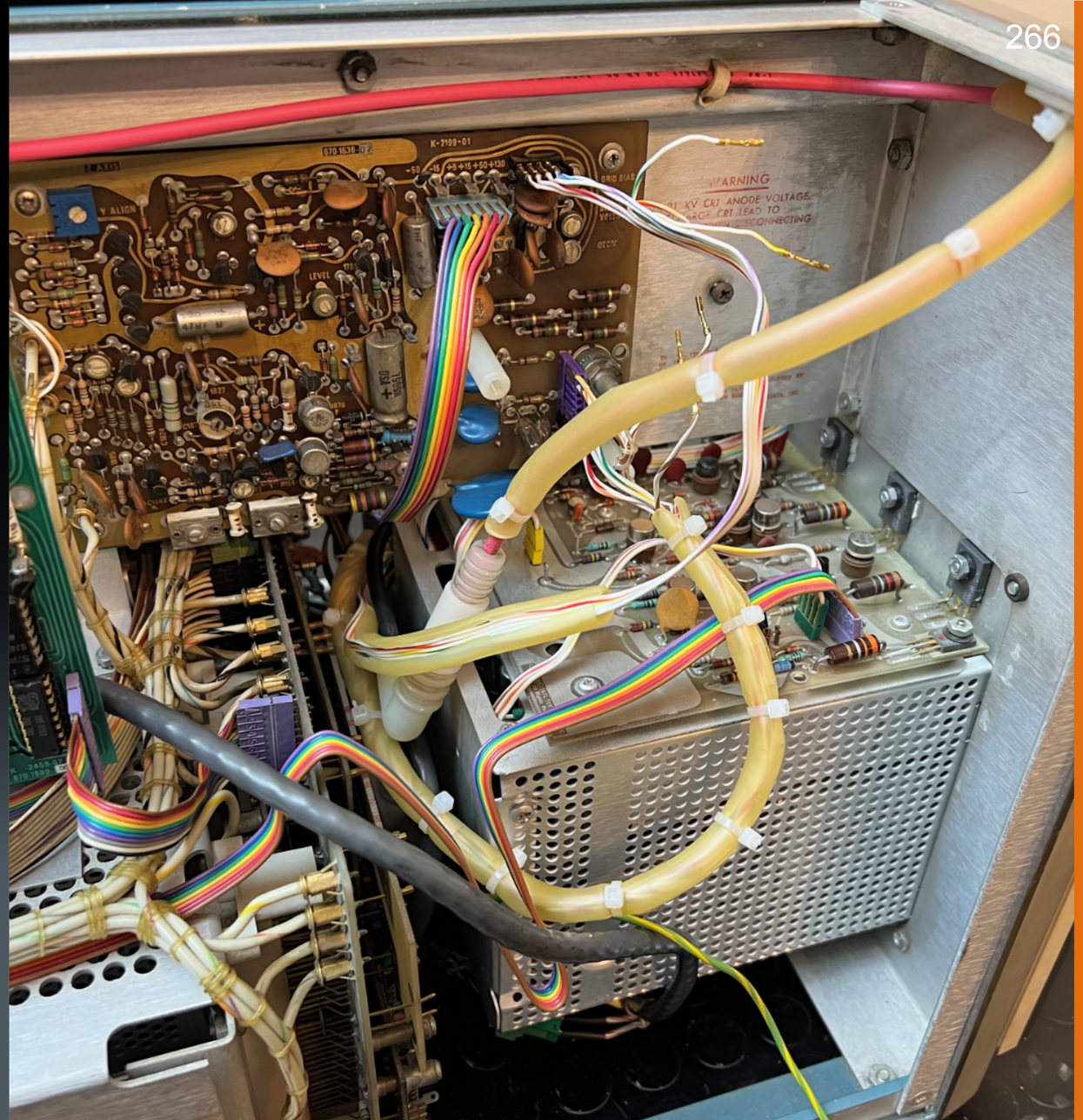











WARNING

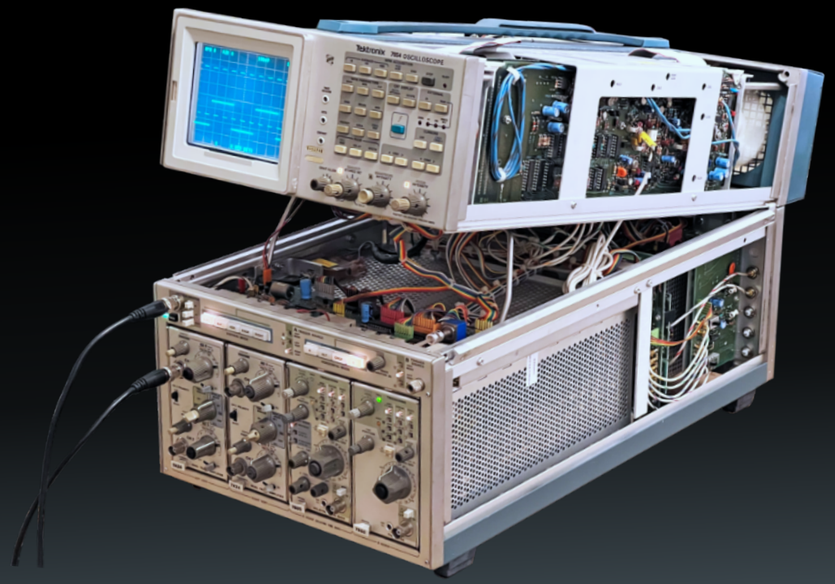
The End of the Battle

Like every wimp, I tried to delay as much I could the dreaded moment of the switch on, but at a certain point I had to do the test. But I afforded this phase gradually:

- first I tested the HEPS with the dummy load I used also for the 7844; the result was excellent: all the voltages were OK, including the HT and the UHT;
- before connecting the HEPS to the mainframe, I checked the mainframe's power supply lines resistance, as suggested by the manuals. It was a good idea, because it allowed me to see that one of the power ribbons was inserted in the wrong connector;
- finally, I installed the HEPS in the mainframe. Note from the photos that I added a latex tube to increase the wires insulation. Ugly but effective;
- I had also to add the main power switch, lacking as well.

The result was not immediately good. A soft "bop" told me that something exploded, but with no smoke. Checking the voltages, I discovered that the -15V was near to zero. After the usual checks, I bet that the problem was C60, the -15V electrolytic capacitor mounted on the main board. Replacing it was not easy, but I won the bet: the electrons started again to flow in its old circuits and the 7904 returned to life.

It was just a **battle**, I know, but I was very happy of the result. The **war** is still long: I soon discovered another very complex problem, but this is a story for another chapter.



Subsection: 7854 Addenda

A repair story of the 7854 HEPS. In the occasion, we analyze also the differences in one of the latest edition of this important subassembly.

7854 Addenda

Shark Mouth

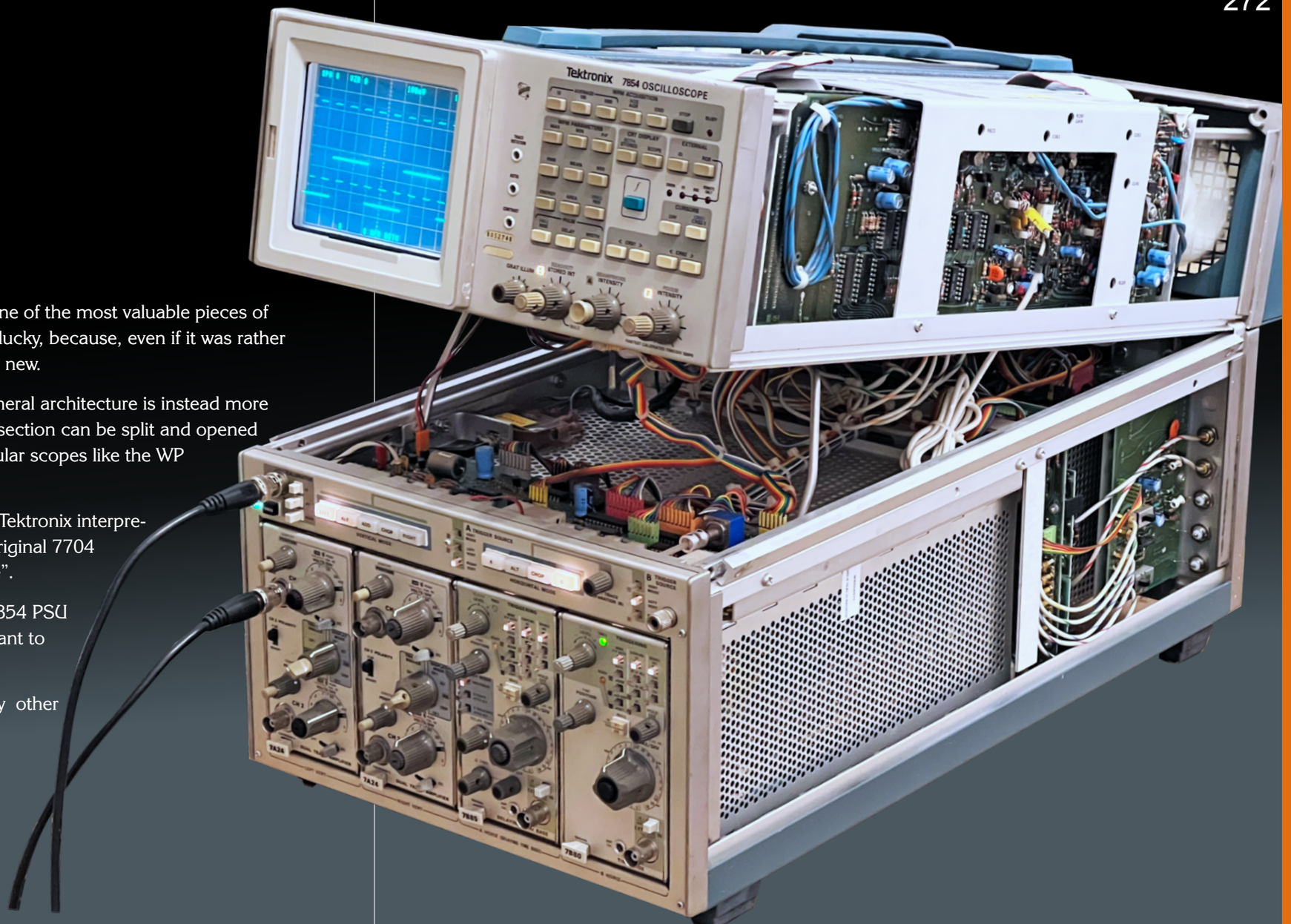
The 7854, together with its programming keyboard, is probably one of the most valuable pieces of my small collection (also from the economic point of view). I was lucky, because, even if it was rather expensive, it and its plug-ins are in excellent conditions, almost as new.

The 7854 looks similar to the previous 7904, 7844 etc. but its general architecture is instead more similar to the 7704A. I call it “shark mouth”, because its superior section can be split and opened like a mouth. Thanks to this structure, Tektronix could build modular scopes like the WP 1100/DPO, described in the mainframes section of this book.

Also the Power Supply Unit (PSU) is rather different. It is the third Tektronix interpretation of the High Efficiency Power Supply theme. Counting the original 7704 (not “A”) as the “type one”, this HEPS could be named “type three”.

As we will see later more in details, the opportunity to study the 7854 PSU subsystem came to me from a problem of my 7854, that didn’t want to wake up anymore.

After this experience, I decided to write this addenda, for the many other enthusiasts of this wonderful model.

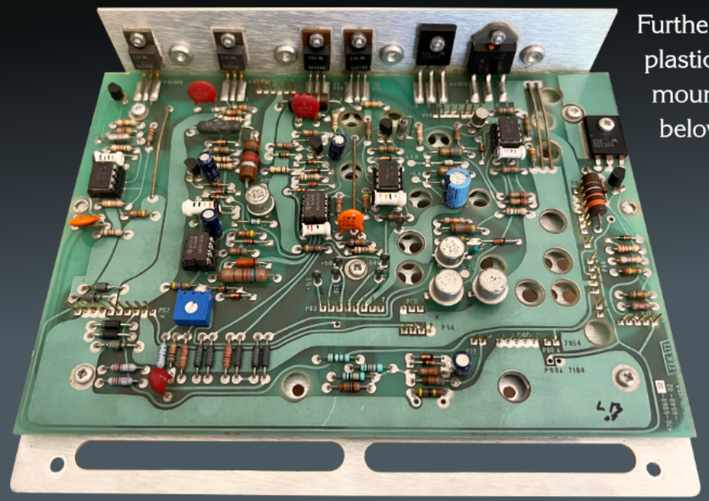


7854 Addenda

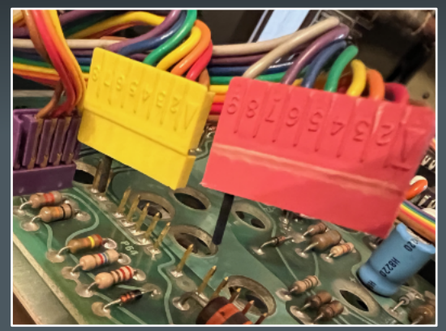
A Revised HEPS

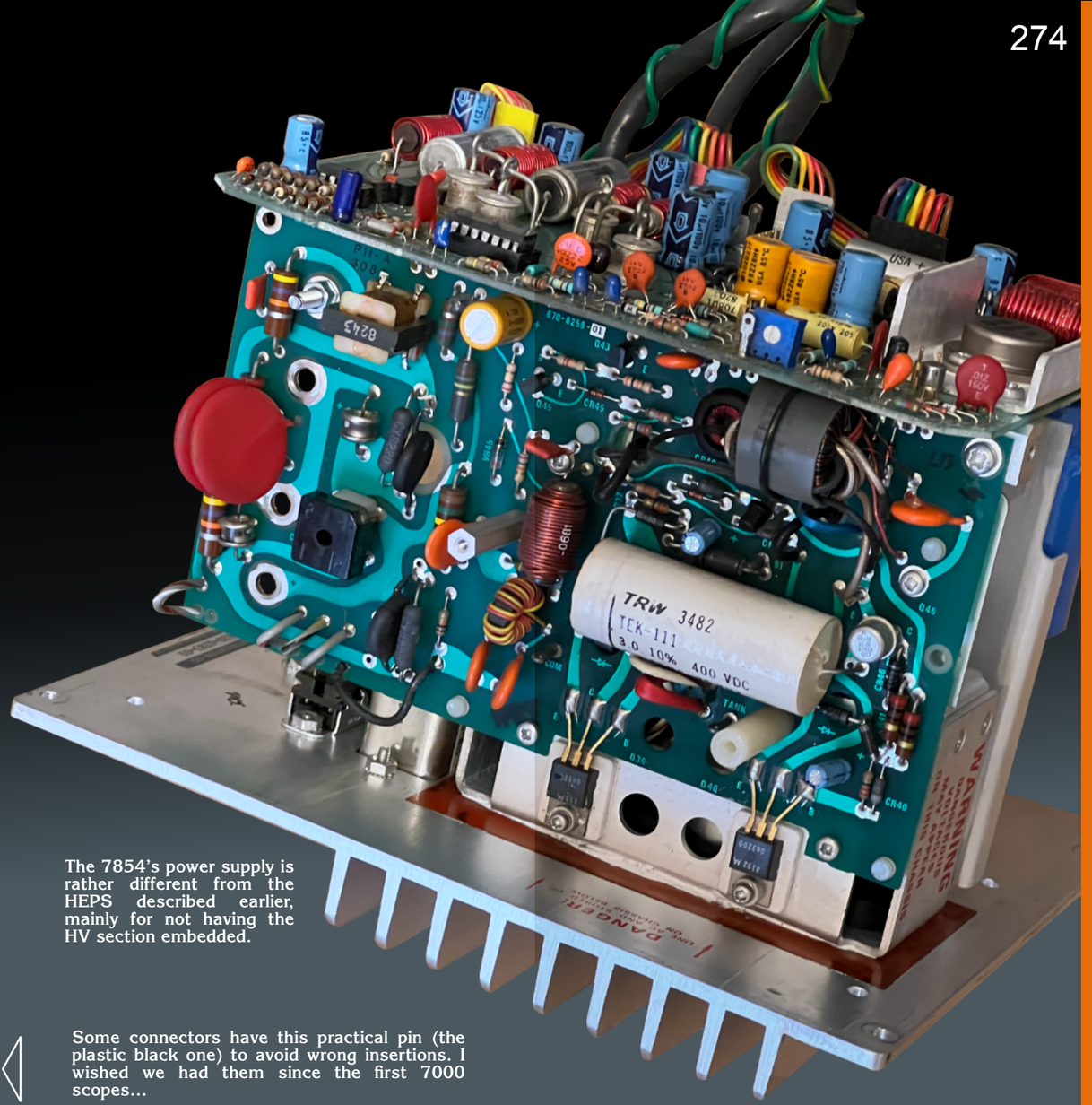
Passing from the type two to type three brought some significant improvements, clearly derived from the experience. Among them, I wish to signal the following:

- the HV section (that we named “the death chamber” earlier) has been removed from the PSU and separated in a dedicated box behind the CRT. This makes easier to access the HEPS inner circuits;
- consequently, the HV section can be disconnected from the PSU, making easier the maintenance. So, it is no longer required to disconnect the resistors, as we suggested before for type two. The bad news is that reinserting the related connector in its place is a nightmare. If only they added three centimeters to that cable!
- it is now easier to remove the Low Voltage board, shown here in the photo below. Previously, the regulator transistors were screwed directly to the rear panel, and so we had to make free each of them to remove the LV board. When reassembling, we had also to apply the terrible thermal paste under each of them. Now there is a metal support with all the transistors, and we need only to remove/remount four screws.



Furthermore, some connectors have now a plastic polarization pin (finally!), to avoid mounting them in the wrong position (here below).





The 7854’s power supply is rather different from the HEPS described earlier, mainly for not having the HV section embedded.

Some connectors have this practical pin (the plastic black one) to avoid wrong insertions. I wished we had them since the first 7000 scopes…

7854 Addenda

Dead?

Few days ago, I switched on my 7454: some of its LEDs had a brief blink and then nothing. Oh no, the pearl of my collection is dead!

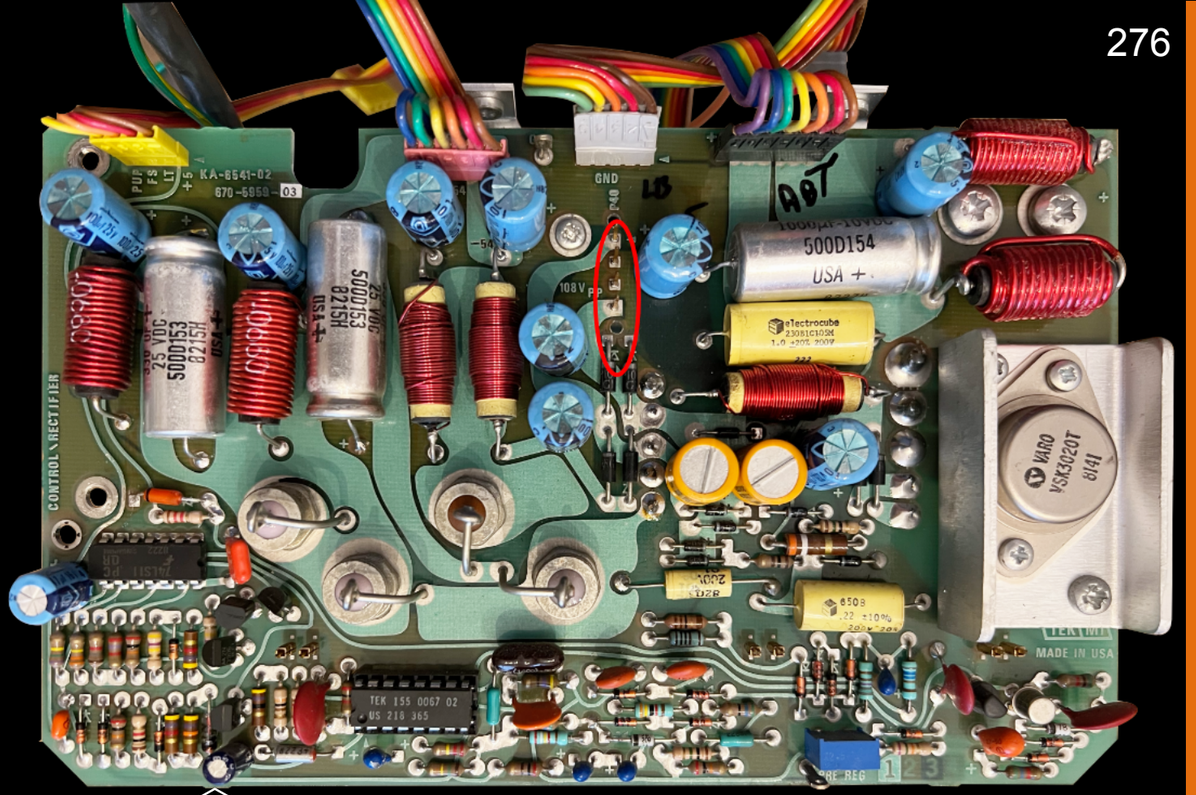
Some noise came from inside, but it was not the classical "click" and I could not classify it. I started some routine checks, but I understood soon that the problem was in the power supply. So I resigned myself to taking it apart and check it. It is not a trivial task, as you know. Eventually, I could extract it partially and remove its metal protections. I tried again and noted a strong flash from the PSU bottom. First I suspected the 4A fuse, that was blown, and I replaced it. Having not a 4A fuse, I used a 2A. New test, new flash, but the fuse remained good and the internal warning lamp continued to blink. Strange. To avoid further damages, I decided to follow the manual suggestions: I got the VARIAC and checked below 30V the leveling filter, the two big 1,000uF 200V C16 and C17 capacitors. Initially, everything seemed to be OK, but the manual says also to check if the voltage across each of them was almost the same. It wasn't. So the hypothesis: one of the capacitor is faulty. I checked them and one had lost its capacity, or, better, it was open.

But why the flash? With a 230 V mains a.c. the voltage across C16+C17 (V1 + V2) is about the peak value of the line voltage, i.e., about 320V, and the mid point is at 160V. If one of the capacitors is open, the voltage across the discharger E8 goes beyond its trigger level and the flash is produced.

I ordered the new capacitors and, in the meanwhile, I decided to recap the other boards (Inverter and Capacitor/Rectifier). When the new capacitors arrived, I decided to reuse the old capacitor cans, refitting them with the new ones. That because these capacitors have also a mechanical function in the PSU structure and the new ones are obviously smaller. I cut them with a saw and, in this way, I could also discover the problem: the internal positive terminal developed some corrosive substance (see photo), which literally "ate" the internal strip connection. The capacitor terminals are aluminum, so I could not solder the new capacitors; I had to drill two holes, that I threaded, for two 3mm screws and used a bit of fantasy. The repair works perfectly and the 7854 is alive again.

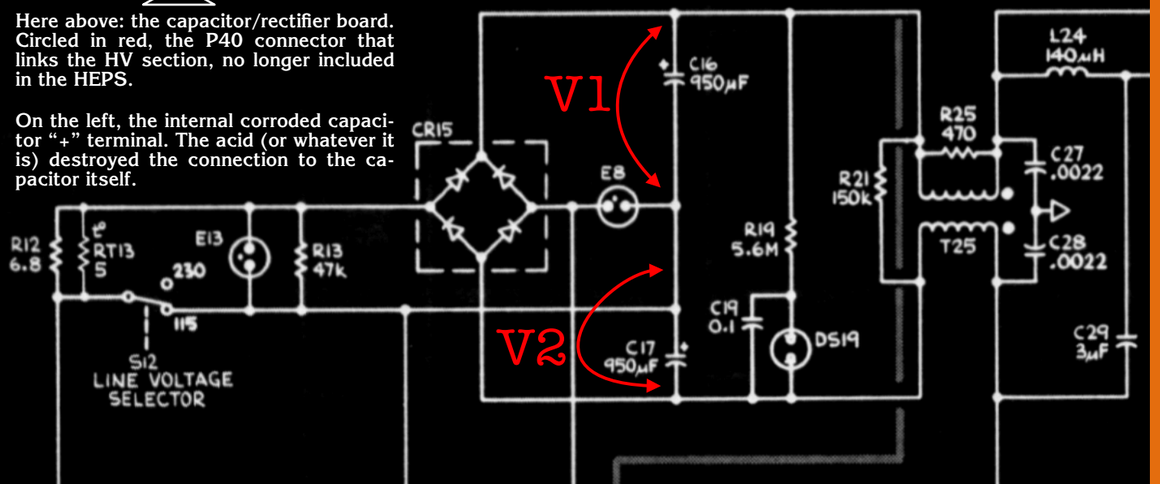


Regarding the fuse, strange that Tektronix recommends 4A even with 230 V line (same as 115V). I replaced it with 2A and it does not blow; I feel more comfortable with this lower value.



Here above: the capacitor/rectifier board. Circled in red, the P40 connector that links the HV section, no longer included in the HEPS.

On the left, the internal corroded capacitor "+" terminal. The acid (or whatever it is) destroyed the connection to the capacitor itself.





Subsection: 7834 Recapping

Recapping is the operation of replacing old capacitors with new one. Here we give some suggestions for the 7834's HEPS.

Capacitors

The effect of time

Capacitors are surely the components that are most affected by aging. Since the development and production of electrolytic capacitors, designers have had to deal with the issues of aging (and, by the way, with the shelf life of these products). Electrolytic capacitors have been around for a very long time, but the rapid increase did not occur until the 1960s, and thus also with our oscilloscopes.

Problems can be:

- change in capacitance;
- ESR and leakage current during operation (with voltage applied);
- reduction of dielectric strength due to degradation of the dielectric (no voltage applied);
- corrosion of the internal electrodes with consequent interruption of their electrical continuity.

It is interesting that when they work (i.e., have a voltage applied), they in someway “regenerate” themselves. If voltage is applied to the capacitor after a longer storage time, this can initially cause an increased regeneration leakage current, that decreases after some time, or produce damages when too high.

All that above is in my experience with Tektronix scopes: often a capacitor bursts after some working minutes or hours, when you switch it on again after a long sleep, or it seems it lost all its capacity for the electrodes interruption.

Capacitors on the loads

Remember however that, in the case of the HEPS, generally the capacitors on the voltage load does not burst, but the HEPS goes in click mode. So, it is advisable to test the HEPS separately with the dummy load, before attempting to repair it.



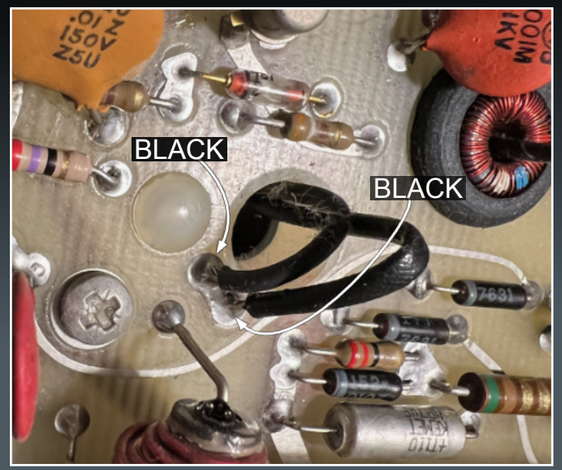
7834 Recapping

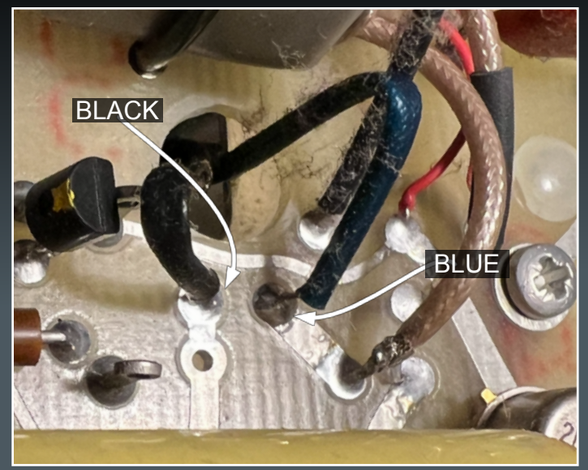
Repair approach

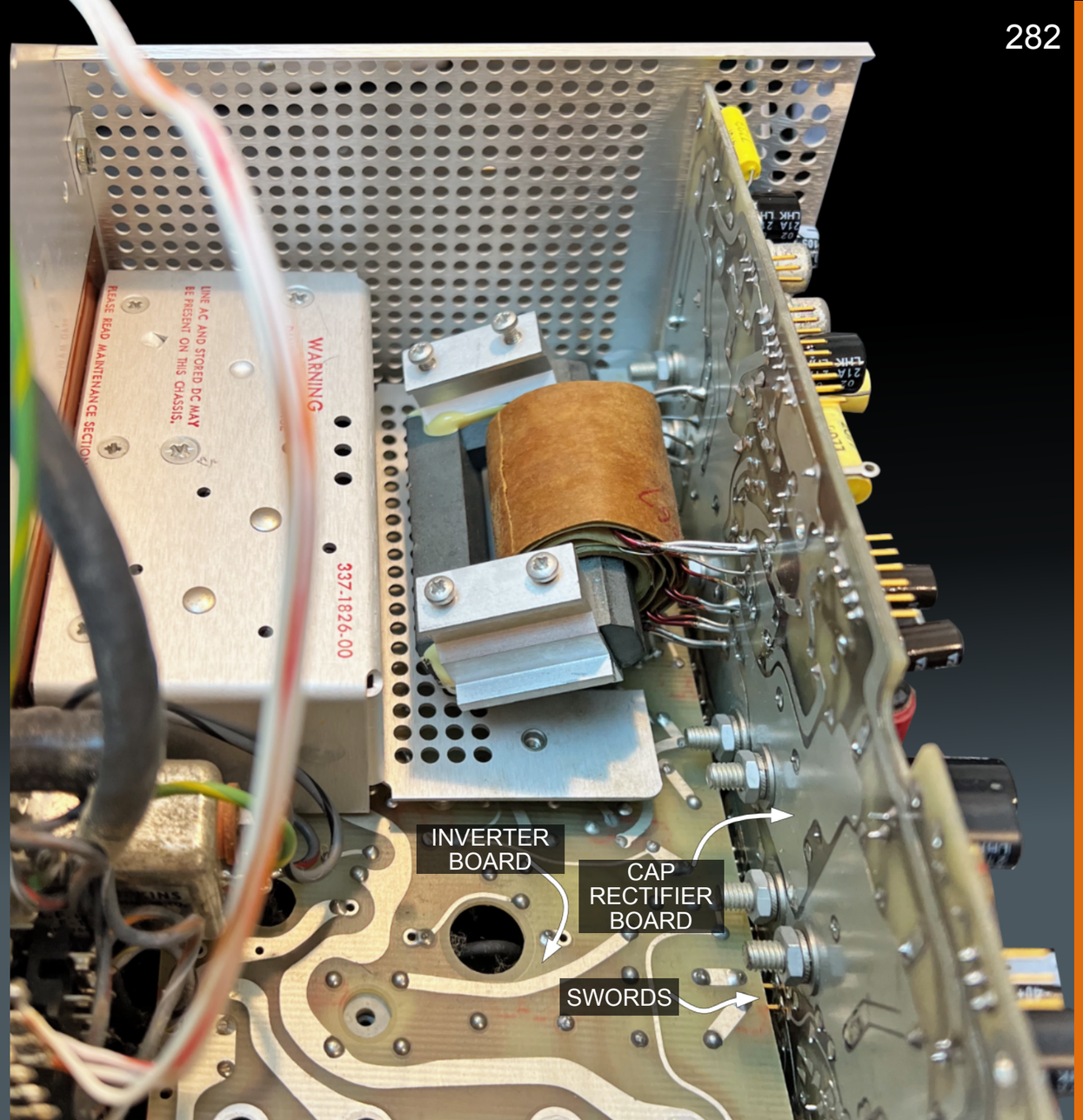
Before starting to squeeze my brain, I decided for a full recap for the 7834 HEPS. The capacitors are inexpensive and not too many. If it turned out that the problem is something else, I had anyway new capacitors installed, which is always a good thing. But, above all, I wanted to stick my nose in it to see what it's like inside and the differences with the other HEPSs I already met, differences that I have partly already anticipated. See my book “Tektronix 7000 Series” for a report on the new HEPS.

Dismantling the HEPS

This job is rather intuitive, less the last part. To make easier the job, it’s advisable to separate the Cap Rectifier Board (CRB) from the Inverter Board (IB). Initially it seems almost impossible, because they are linked by the transformer. But, if you look closer, the transformer is connected mainly to the CRB, while toward the IB there are only four wires, not difficult to unsolder (see the photos).







The Dummy Load

Simple and useful

A **dummy load** is a tool that charges the outputs of the HEPS to test it independently from the oscilloscope, allowing us to understand if a problem is in the power supply unit itself or in the mainframe.

Building a dummy load is rather easy; the table below describes mine. Don't forget to add a suitable 100 uF electrolytic capacitor on each wire, and to connect the related SENSE line to each voltage.

An important caveat

It is important to note that the 7834 HEPS' output connectors (i.e., the one used to delivery the power to the mainframe and the one to sense the voltages) are diabolically slightly different from the others we already met (7904 and 7844), but seem diabolically similar.

The table on the opposite page shows the differences. Therefore, if you already built the dummy load for testing the HEPS independently from the mainframe, you'd better checking the table carefully.

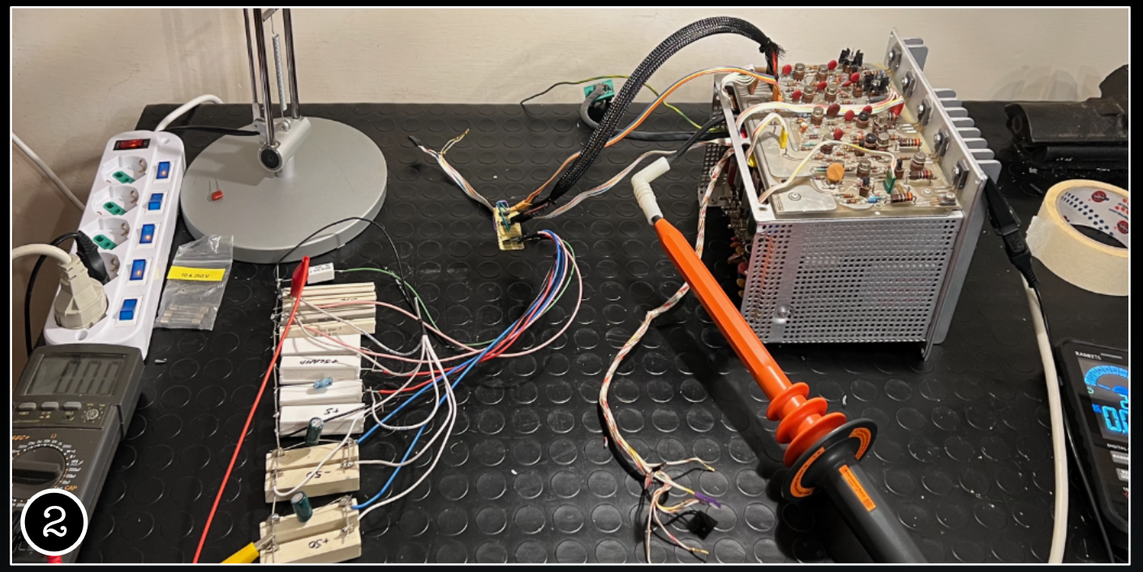
❶ **The components for building the dummy load.**

❷ **My dummy load is dreadful but does its duty.**

❸ **The 7844/7904 HEPS connections compared to the 7834. It is not necessary to build a new connection but it is sufficient to mount the flat cable connectors properly shifted.**

Voltage	R1	R2 (in parallel to R1)
+50V	330 ohm 30W	270 ohm 30W
-50V	330 ohm 30W	270 ohm 30W
+5V	10 ohm 20W	10 ohm 20W
+5V LIGHTS	10 ohm 20W	10 ohm 20W
+15V	27 ohm 30W	33 ohm 30W
-15V	27 ohm 30W	33 ohm 30W
+130V	6K8 ohm 5W	

❶



❷

7844 PIN	7844 P1482	7834 P1482	7844 PIN	7844 P1483	7834 P1483
					POWER ON
1	+130V		1	I SENSE	I SENSE
2	LINE TRIG	LINE TRIG brown	2	GND	GND
3	+5V	+5V red	3	+5V SENSE	+5V SENSE
4	-15V	-15V orange	4	-50V SENSE	-50V SENSE
5	-50V	-50V yellow	5	+50V SENSE	+50V SENSE
6	+50V	+50V green	6	-15V SENSE	-15V SENSE
7	+15V	+15V blue	7	+15V SENSE	+15V SENSE
8	GND	GND			
9	GND	GND			
10	LIGHTS COM	LIGHTS COM			
		+5V LIGHTS			

❸



Subsection: HEPS not Guilty

Obviously there are situations where the HEPS goes in click mode but the problem is not in the HEPS itself, but in the mainframe. To come out of that, the HEPS knowledge can give you a hand.

Another possibility, another addenda (7834, but not only)

HEPS not guilty

Obviously there are situations where the HEPS goes in click mode but the problem is not in the HEPS itself, but in the mainframe. To come out of that, the HEPS knowledge can give you a hand.

A real case

I personally experienced that recently. Imagine having just repaired a gorgeous 7834 storage scope, which runs perfectly, and that at a certain moment the traces get darker and darker, and the HEPS goes in click mode. Initially I underestimated the problem, thinking “just another capacitor in the mainframe” (those of the HEPS had already been replaced by me). But the problem was much tougher and required a lot of time to be understood.

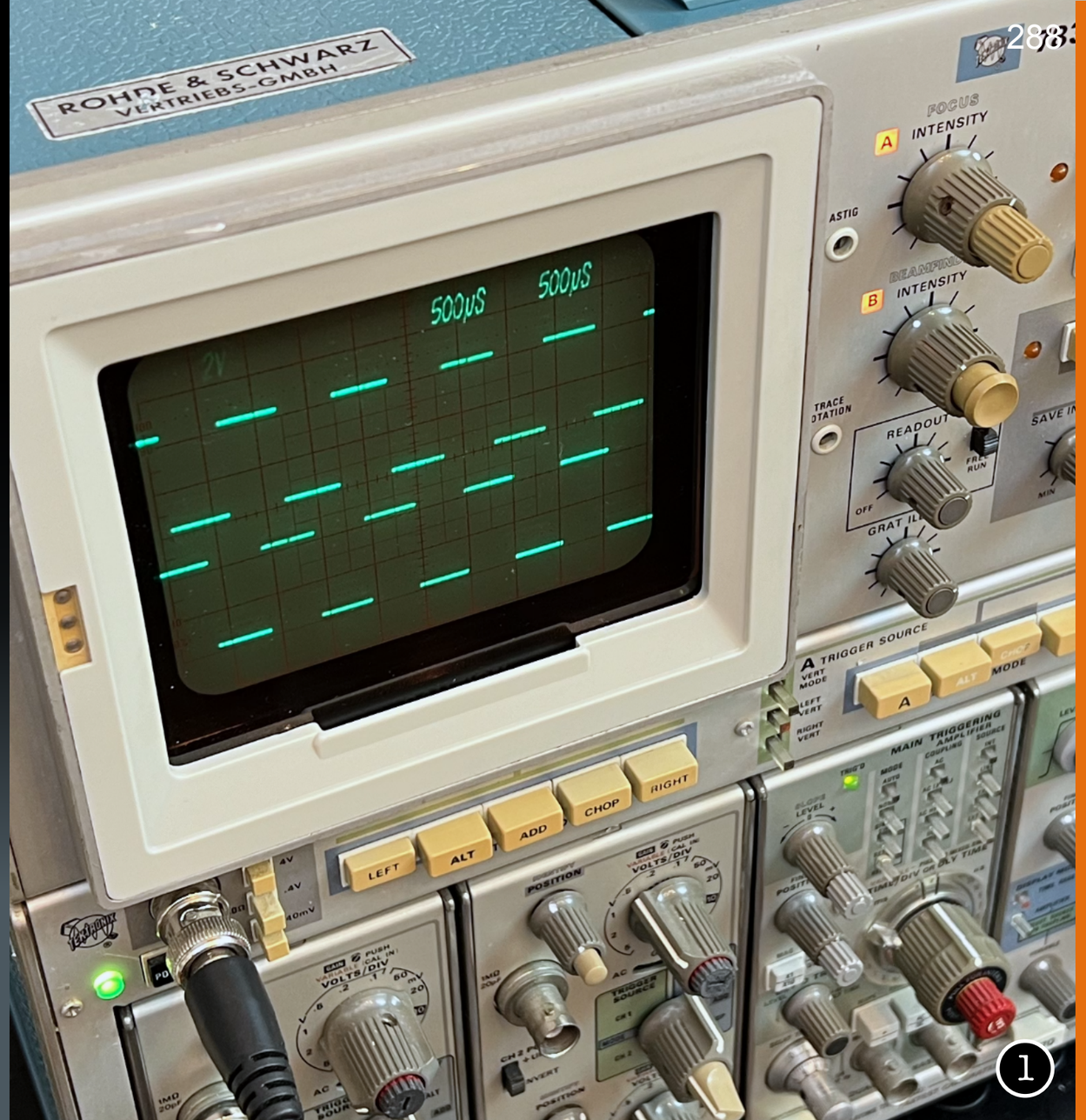
First checks

The first thing to be checked, is, of course, the HEPS itself, disconnecting it from the mainframe and connecting it to our dummy load, as described earlier. So we assume that the HEPS is properly functioning and that the problems arises only with the mainframe.

The second thing to do, is measuring the resistances on each of the voltage lines (+15, –15, +50, -50, +5V). The manual reports the expected values. But what to do, when if these values seem to be correct?

❶ The poor 7834, two hours before falling ill.
❷ Test points on the HEPS Capacitor Rectifier Board.





The HEPS can help us

There are many ways in which the HEPS can help us. I am going to describe here that which seemed to me to be the simplest. To be honest, it took me some time to define it, and I am going to tell you only the final results.

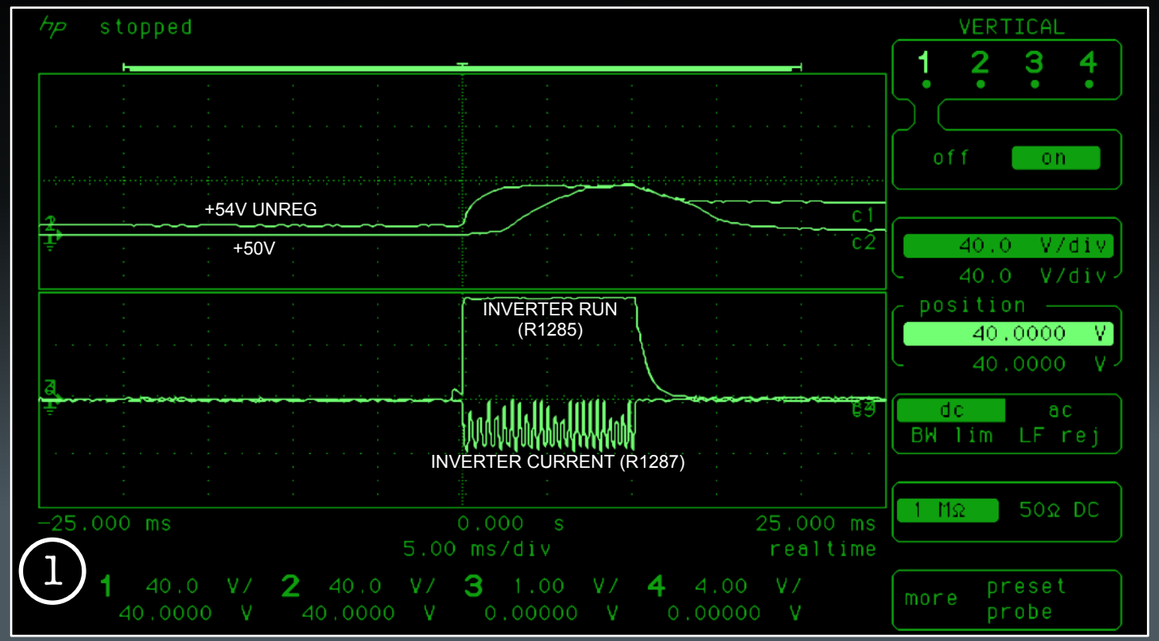
The click mode

The click mode is much more genial than it could seem at first sight. It gives us the way to find a defective component before it bursts, preventing serious damages to our beloved scope, with a cyclic, non-destructive, repeatable attempt to go into service.

What is it happening?

To diagnose the patient, we can do an electrocardiogram to it. The picture on the previous page gives points where the electrodes must be applied, and the image below shows the oscillograms. Above you

Here above: the capacitor/rectifier board. Circled in red, the P40 connector that links the HV section, no longer included in the HEPS.



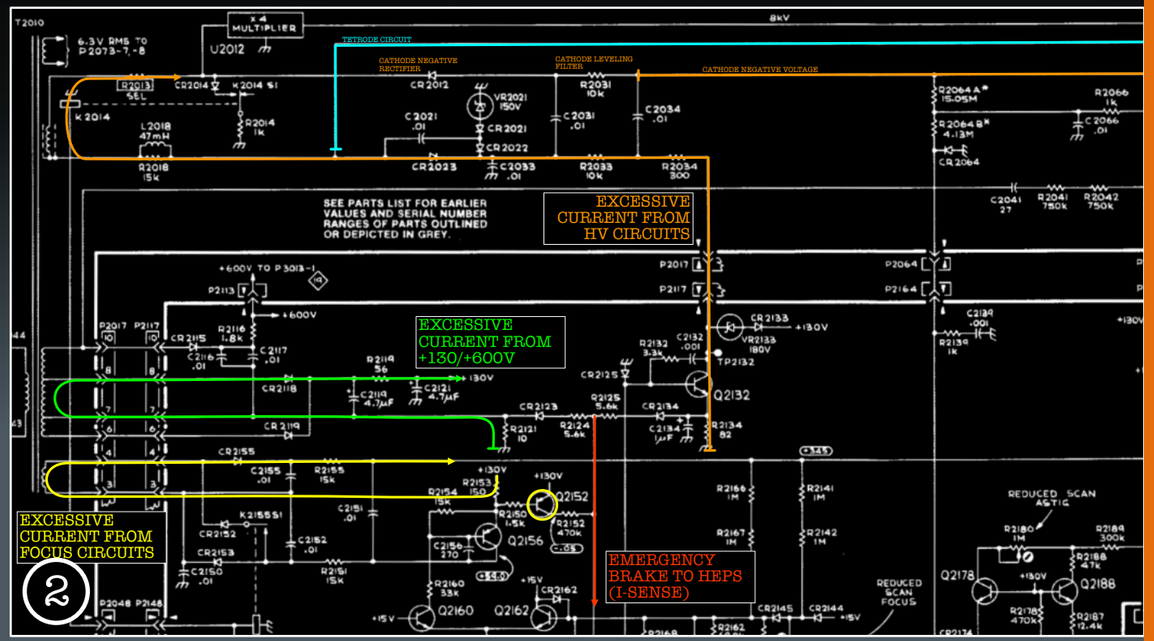
can see a sample voltage behavior, the +50V in this case, the unregulated input to the Low Voltage Board and its stabilized output to the mainframe.

Below, the INVERTER RUN SIGNAL on R1285 (almost the complement of INVERTER STOP signal on pin 8 of U1275). Still below, the INVERTER CURRENT. We have already described it (page); it can supply useful information of the current global output loading, in this case it just confirms us that the inverter is running.

The emergency brake

In the diagram, things seem to go, initially: the unregulated voltage starts raising and the regulated follows, but someone pulls the emergency brake and the inverter stops, before being arrived to damage something (thanks, Tek!). We already described this mechanism in the previous part, but now we will analyze it even more deeply.

The concept is simple: who designed the HEPS provided it, not only with a safety control for the current it produced, but also the external input we called “emergency brake”. When you rise it just positive the I-SENSE line, the inverter stops, and in most cases no damage is produced. If the HEPS internal behavior is clearly defined, the emergency brake pulling depends on the mainframe design.



Let's concentrate on the 7834

In the case of the 7834 (schematic below) three possible circuits can issue the alarm. Referring to the schematic of the A23 FOCUS BOARD, you can observe that the alarm can be issued by:

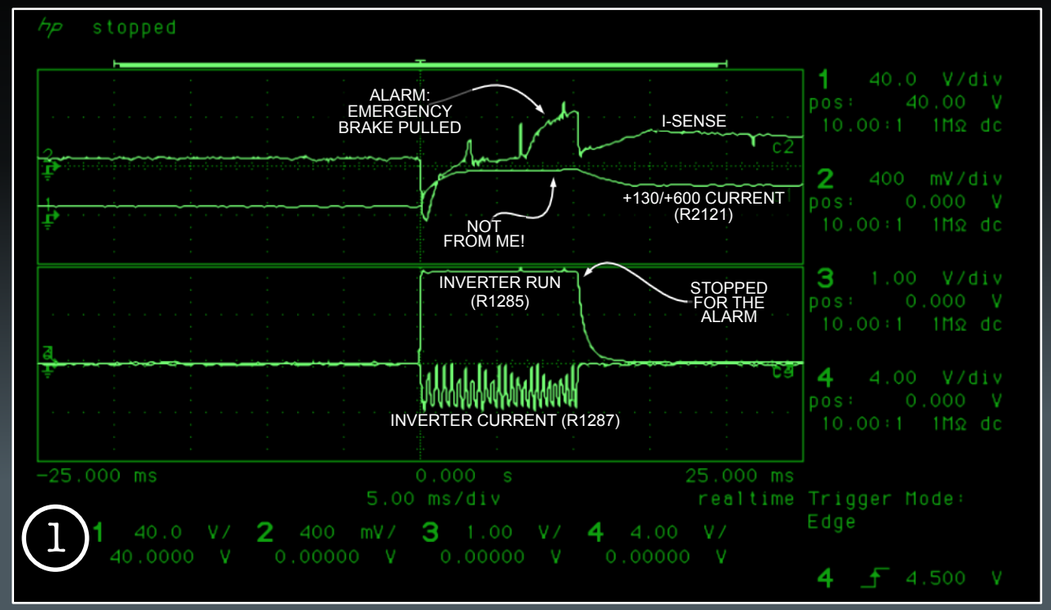
- an excessive current flowing in R2121 (green), i.e. from the +130V / +600V circuit (in the 7834, the +130V is not produced by the HEPS but by the High Voltage section);
- an excessive current flowing in R2153 (yellow), i.e. from the focus circuit;
- an excessive current flowing in R2134 (orange), i.e. from the High Voltage section.

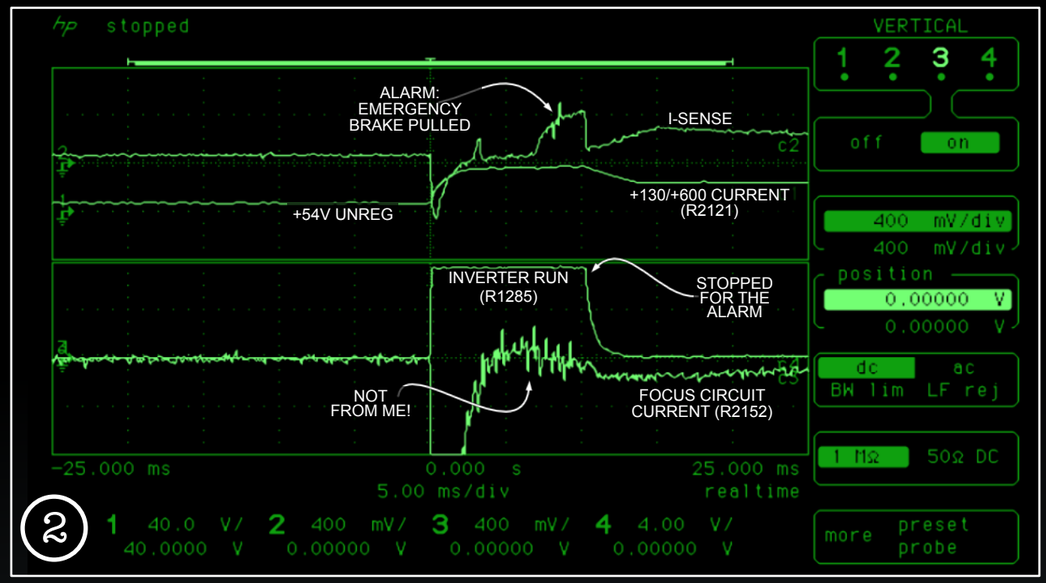
I was rather scared by this intertwining, but, when you understand it, it is easy enough to catch the culprit. You just need:

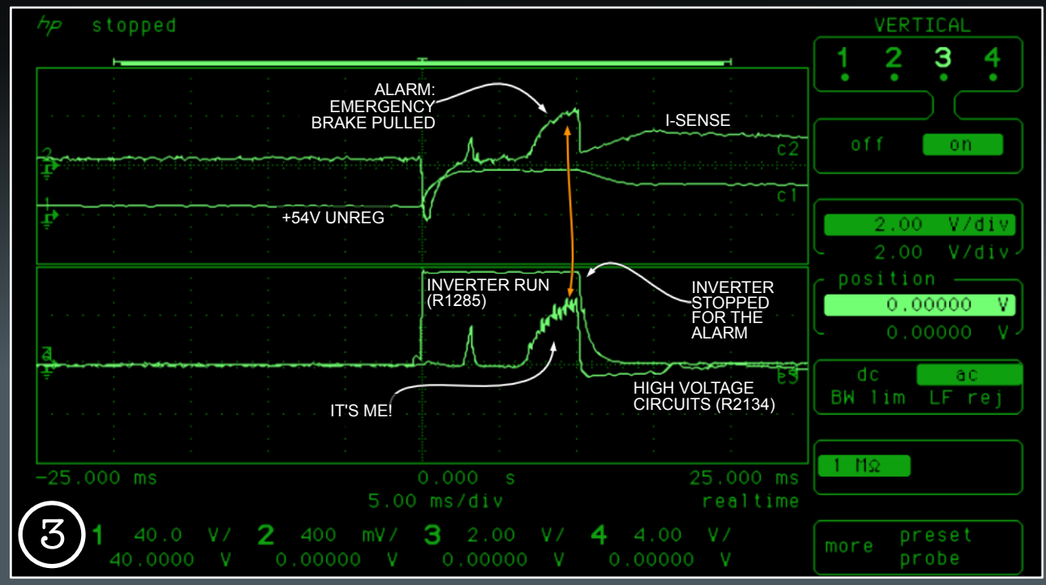
- to "photograph" the I-SENSE alarm on a trace of the oscilloscope;
- watch what is happening on the above said resistor with another probe.

You can see the three photos in these pages. In ❶ you can see the alarm pulse in the I-SENSE line, compared with the signal on R2121. It is evident that the alarm does not come from it.

In oscillogram ❷, we compare the I-SENSE line with the focus circuit current. This is not the brake puller either. But in ❸ …got it! the signal across R2134 has the same shape of the I-SENSE alarm.







❶ Checking the current of the +130V / +600V power supply. It is not it requesting the inverter stop.
❷ The current across R2152 shows that the focus circuit is not the culprit either..
❸ Got it! The High Voltage section is that from which the alarm is generated.

Completing the investigation

We have seen how the HEPS helped us addressing the lead to the fault area. I summarized all the process in few words but it really took me a day and a half of intense investigation and brain squeezing to laboriously arrive there, but this was only due to my inexperience. Someone more knowledgeable than me could probably do that in a short time, confirming the power of the scheme defined by Tektronix.

Apart from that, we did not yet fix the oscilloscope, which remains faulty, but now we knew at least in which area the problem was.

I feared to need to afford a new long battle, like that which led me to this point. The offending circuit provides the 2 kV voltage for the cathode, the potential for the control grid, and the 8 kV Post Deflection Acceleration (PDA) voltage.

Before starting the new battle, even with no hope, I decided to try the easiest possible action: to disconnect the PDA voltage multiplier. Surprise: without the voltage multiplier, the click disappears and all voltages rise to their proper value. So the culprit is manifestly the U2012 voltage multiplier sealed module.

An impossible repair

That is good, from one side, because we got the problem, but from the other side, how to repair a sealed module? Impossible.

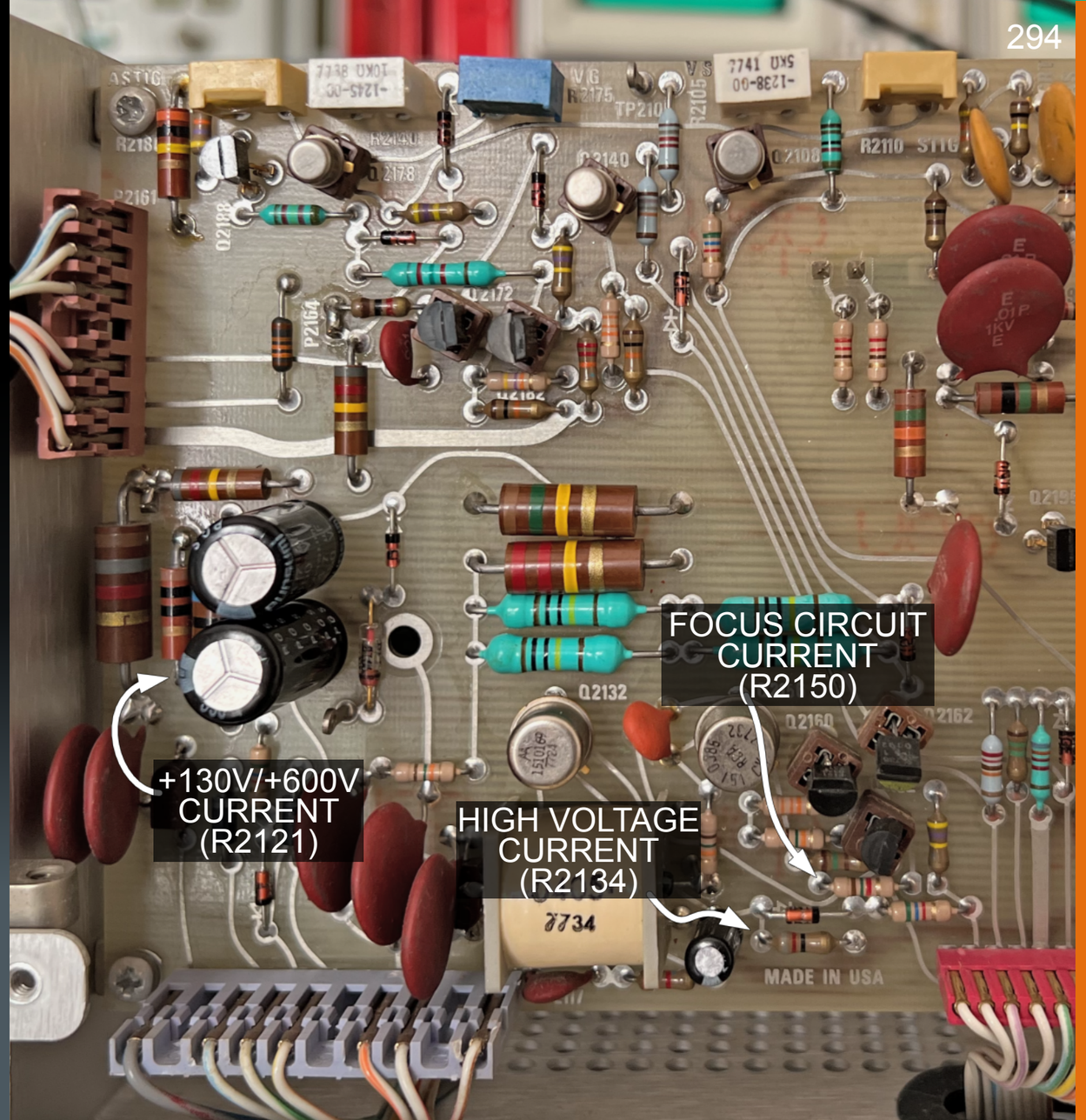
So I started wandering in my cellar to find some possible substitute of U2012. I had three candidates: one from a 7704, one from a 7603 and one from a 475. I was uncertain if attempting this transplant, but then I thought “in the worst case, it will continue clicking…”.

The first attempt was with the 7603 multiplier, nominally x4 like the faulty one. The experiment did not fail completely: the 7834 started again to leave, but the traces were very “washed out”. I measured the PDA, it was only 4 kV instead of 8. No wonder.

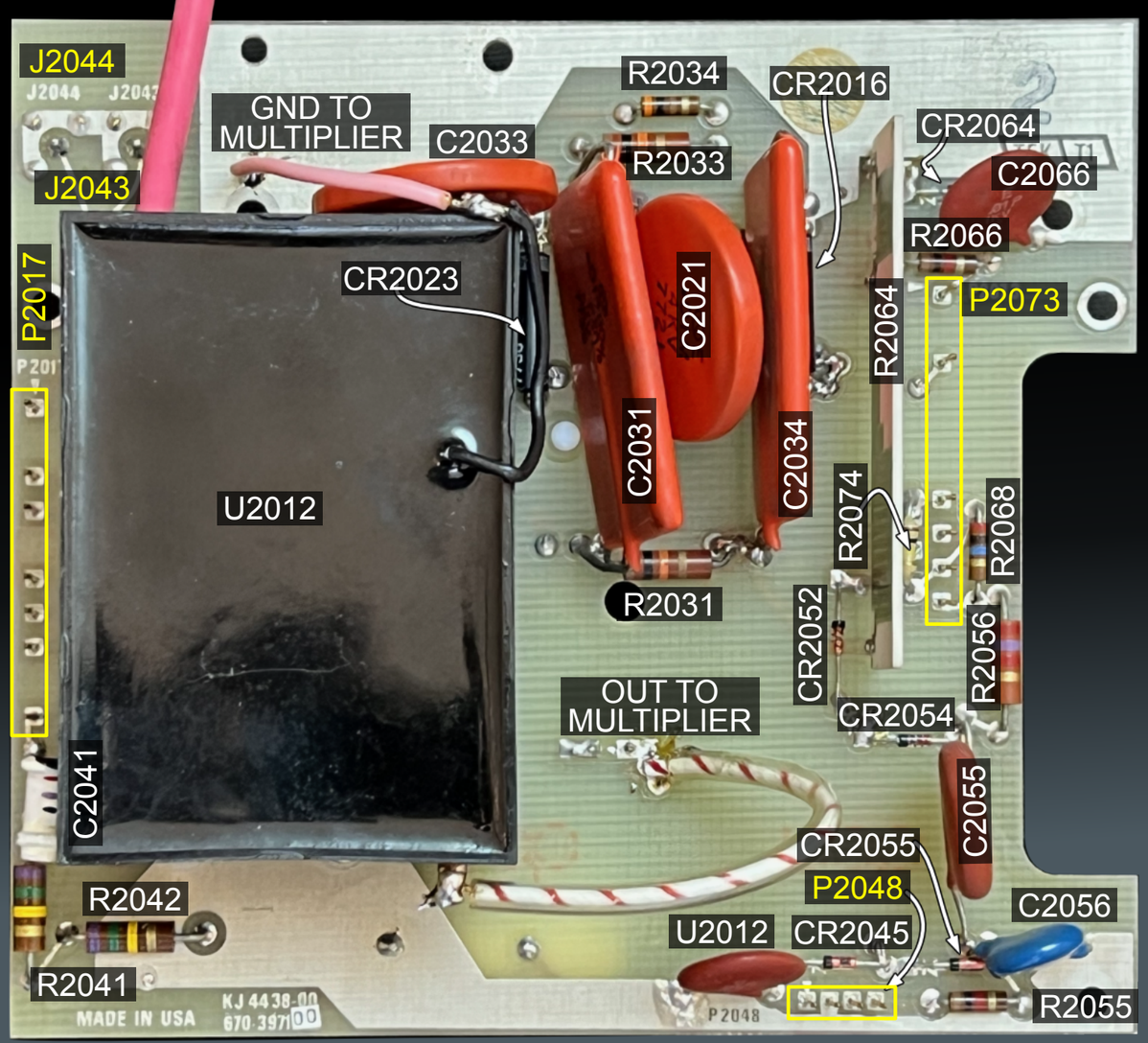
Then I tried the 475’s one; it was much better from the mechanical point of view (the two are almost identical) and the effect was surprising: the CRT image was ultra sharp, but the voltage was excessive (11,5 kV), so I immediately switched it off, but happy, because I knew that solving this point, the 7834 can return to full functionality.

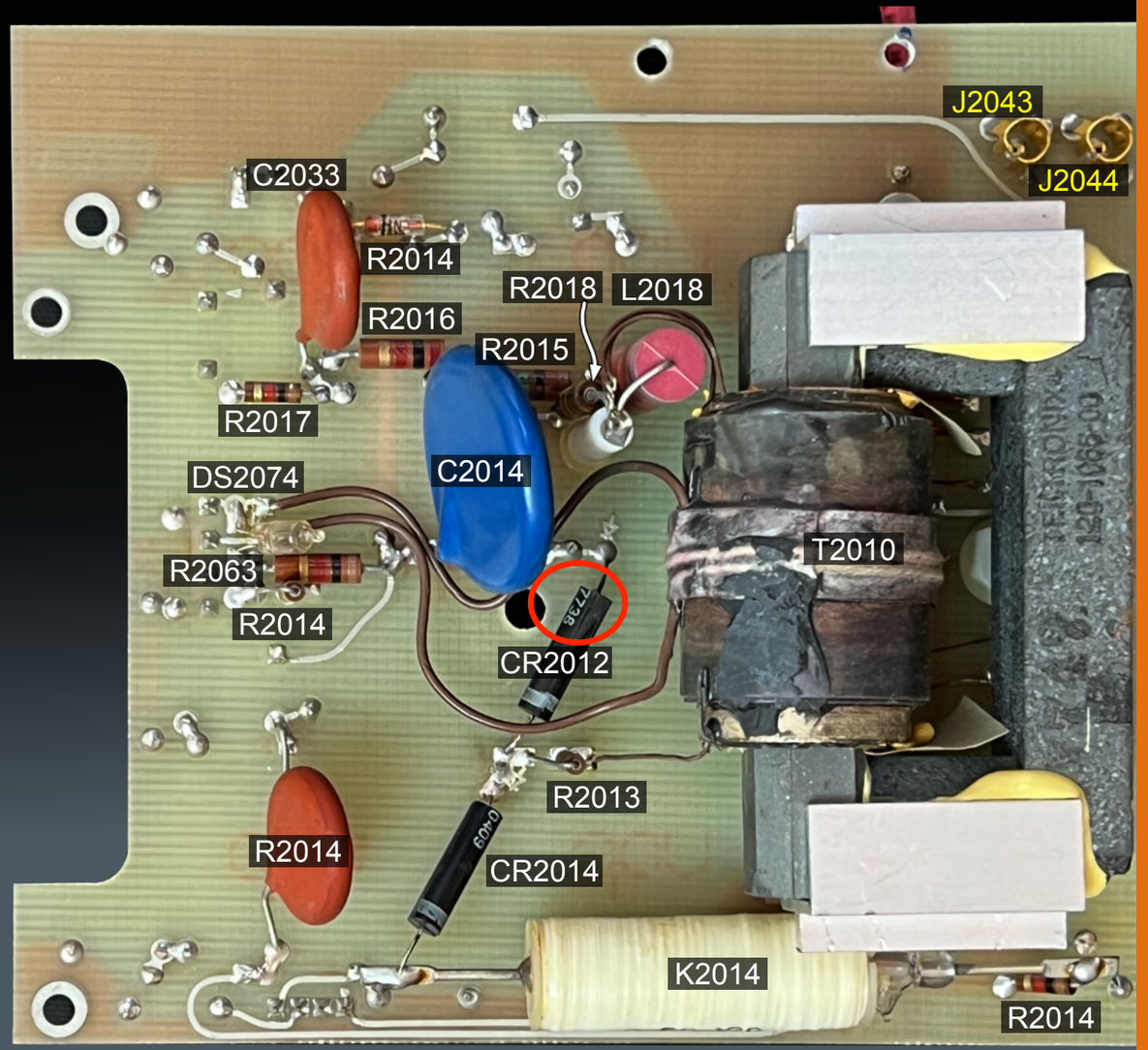
A very kind person from Tekscope (GroupIO), offered me a new original transformer. I thanked him and now I am waiting for the new transformer. I can’t wait…

On the right: the 7834 A23 FOCUS BOARD, with the test points referred in the text.



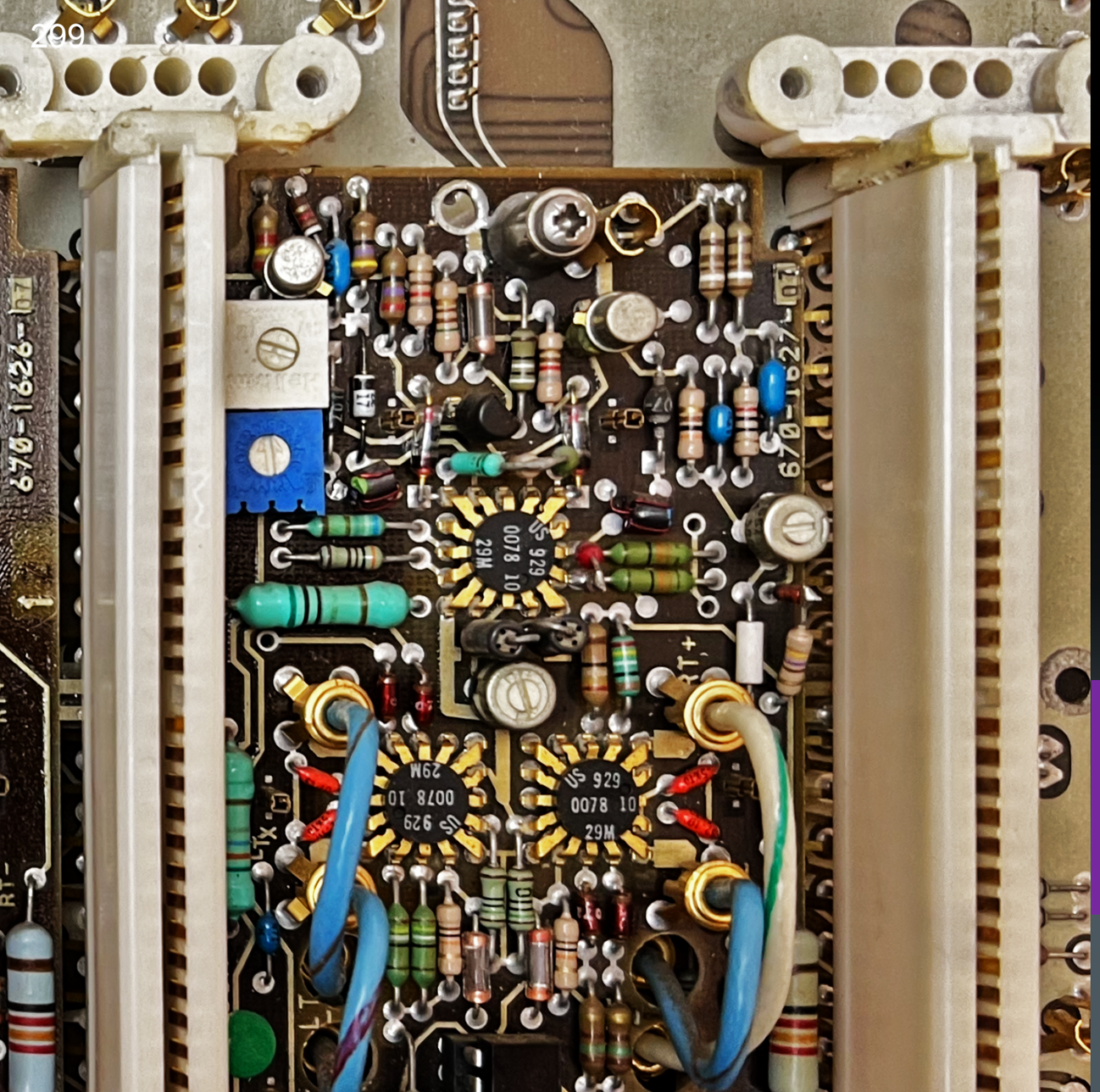
7834 High Voltage Board





Z-Axis Board


R O FOCUS
R2315
GAIN RS
R2320
J2316
Q2362
Q2382
Q2302
Q2306
R2366 FS
Q2372
KK-4437-00
670-3970-00
J2208
J2203
U2224
RCA 740
Q2384
R2425
R2435
GND
CAUTION 4KV
UNDER COVER



7000 Series

Plug-in connections

The plug-in connectors are much more “technological” than you may think, and clearly Tektronix did a good job with them, if half a century later most of them still work properly. I definitely underestimated this kind of problem, that I never met after restoring several Tektronix oscilloscopes. It is like for our body: there are parts of it that you never mind until they start to trouble you.

Plug-in Connectors

A new beast to afford

Talking about the 7904 HEPS, I concluded saying that It was just a battle, and that the war would be long. When I wrote it, I was very dejected; I had just finished the 7844 power supply implant in the old 7904 scrap, and I was immediately facing a new problem, that seemed to me to have no solution: the plug-in connectors on the Main Interface Board (that I will call MIB from here on out) were faulty. I tried some heuristic solution, but soon understood that a new major surgery was due.

I definitely underestimated this kind of problem, that I never met after restoring several Tektronix oscilloscopes. It is like for our body: there are parts of it that you never mind until they start to trouble you. We (…I) are used to insert and extract plug-ins without thinking what happens inside the scope in the insertion point.

The plug-in connectors are much more technological than we think, and clearly Tektronix did a good job with them, if half a century later most of them still work properly.

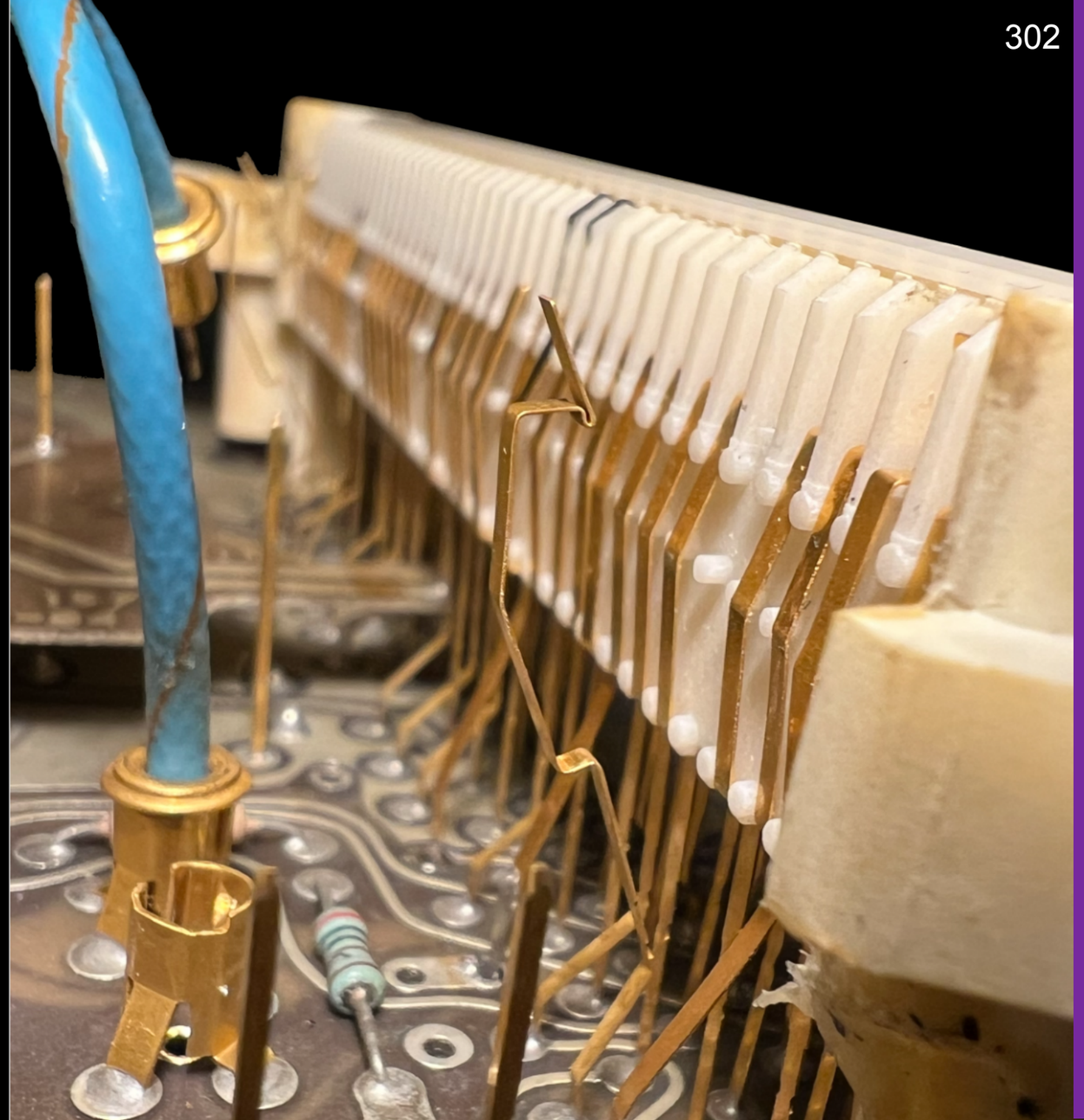
The beast

Let's now return to my sadness after the discover. Time base A was producing half scan (see the photo) but, slightly moving the plug-in, it went to full. Time base B was completely dead. *I will never will be able to fix this problem, it's better to give up, etc.*

Disassembling the MIB seemed to me like an impossible mountain to climb, with all those hated coaxial connectors. Then I thought: what do I have to lose? Let's try…

The job was not easy, but however possible. But the real scaring aspect was think to reassemble it. I took a lot of photos, which later demonstrated to be very useful.

In the photo: a plug-in connector with removed cover. In evidence a bent pin, which creates contact problems and inhibits the plug-in extraction (acts like a hook). Note also the dreaded coaxial connectors which require extreme care when inserting. The first in the photo is not a connector and the wire was soldered to the board (you can see the empty pad now). As explained in the text, I broke one by pulling it as it was a connector.



An accident in the accident

At this point, an accident in the accident arose: one of the coax connectors would not extract. I pulled more and more strong and the cable jacket only moved respect to the internal wire. The jumper was irremediably destroyed. My morale felt in the ground (I later discovered that some on these jumpers are soldered on on side; I believe he wasn't coming out!).

The Main Interface Board

Finally, the MIB was in my hands, and I could understand why its photos on the Internet are so rare; on the next page the MIB from the front side, while here on the right you can see it still mounted inside the mainframe.

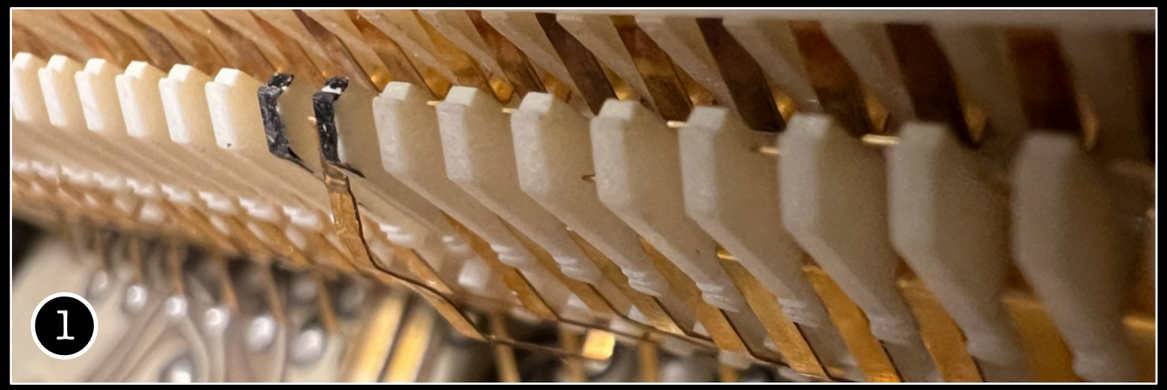
More than a board, it is a multi-piggyback sandwich. Each board is connected to the others by the typical Tektronix “swords” and by terrible coax jumpers. Working on it is definitely difficult.

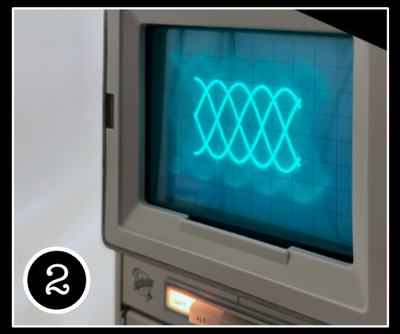
Connectors

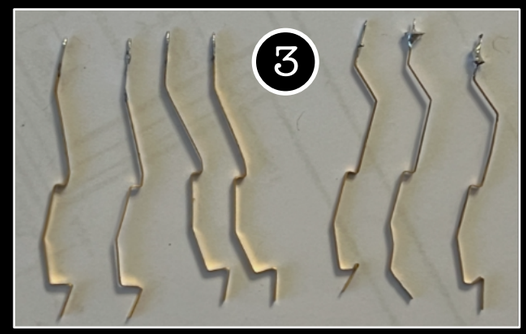
Plug-in connectors are not commercial products but Tektronix’ special design. The are made by soft-springed blades kept in pressure by plastic covers. Over the time, the covers tend to deform or break, and reduce the spring pressure. You can find suggestions about the repair here:

- https://w140.com/tekwiki/wiki/Repairing_7000-series_plug-in_sockets

In addition, it may occur that the blades break or ply (see for example those in the photos).





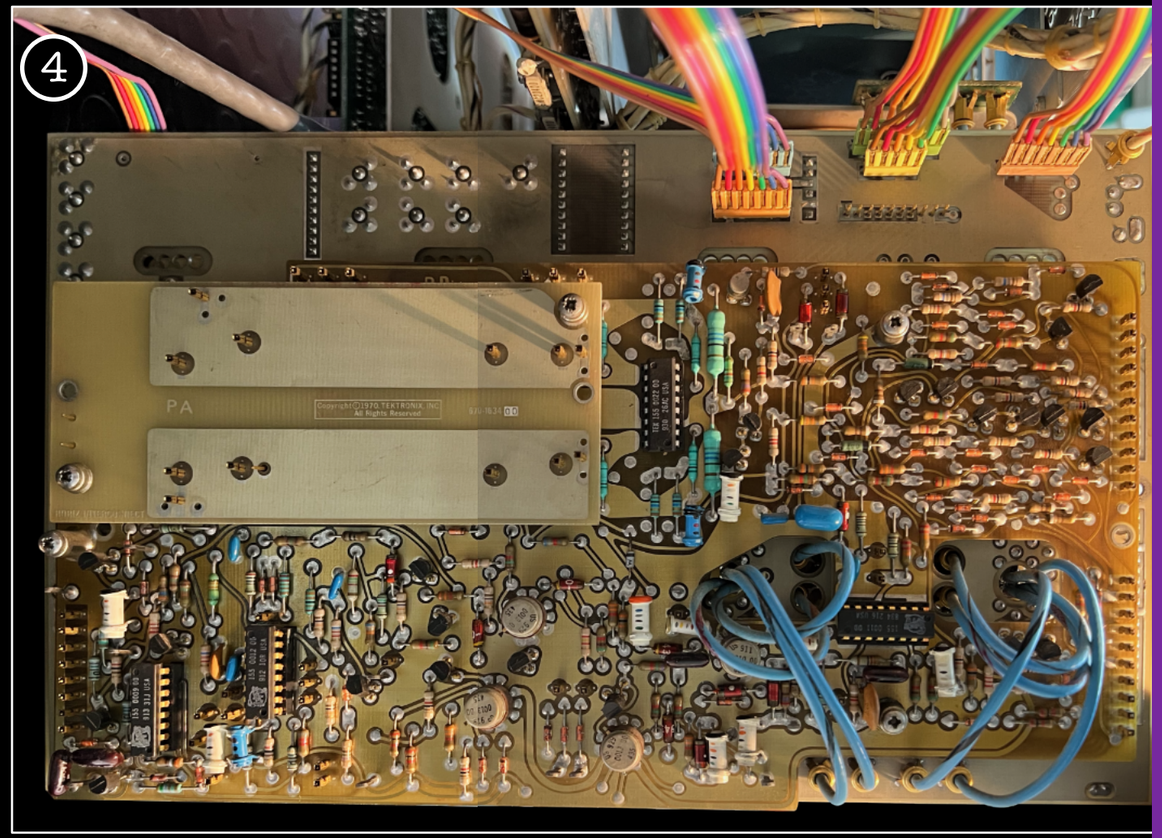


❶ Another example of a bent pin.

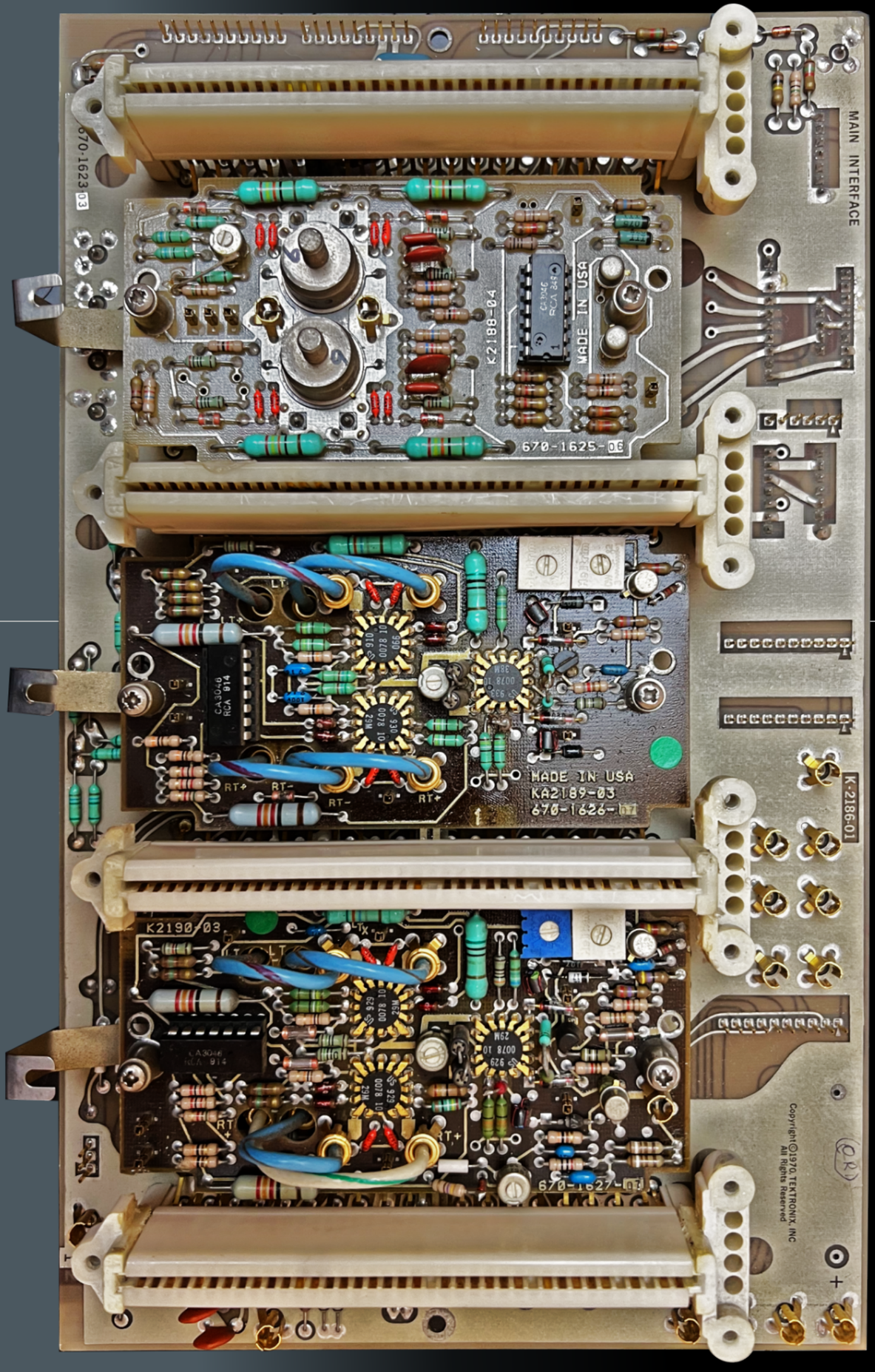
❷ The effect of some faulty pin on the horizontal scan.

❸ Good (left) and broken pins. Note that those from the 7704 have a different but compatible shape.

❹ The Main Interface Board still installed inside the mainframe.



7904 Main Interface Board



How to repair them?

My repair was based essentially in trying to restore the original status as much as I could. To do that, I used pins recuperated from the poor 7704 (see its story on the 7000-Series book), which had dozen of still usable pins, and a selection of the connector covers from many I had. Much patience is required, but the work can be done. Check each pin with something like a needle. The tip must freely move. If stuck, the pin must be replaced.

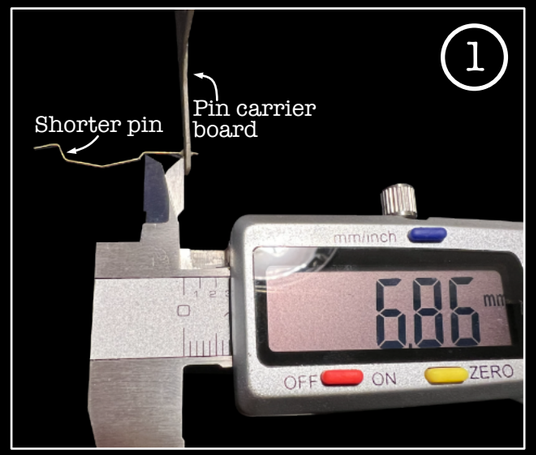
Few pins (TRIGGER+/TRIGGER-) are mounted on an intermediate board and are shorter than the others. They must be adapted manually (see the photo for their exact lengthl).

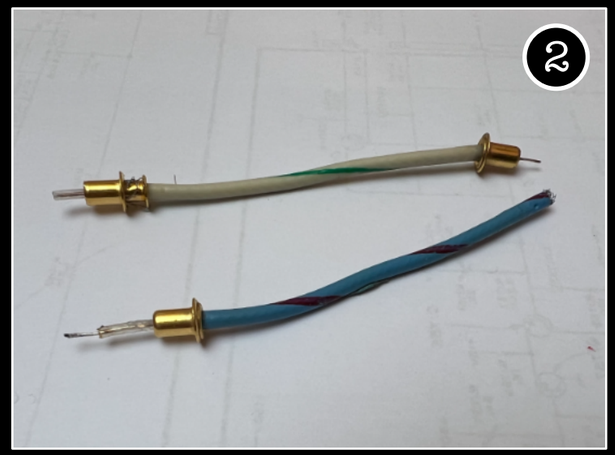
I had also to fix the broken coax jumper. I rebuilt one, by using an old coax from the 475 (see the photo below).

Final testing

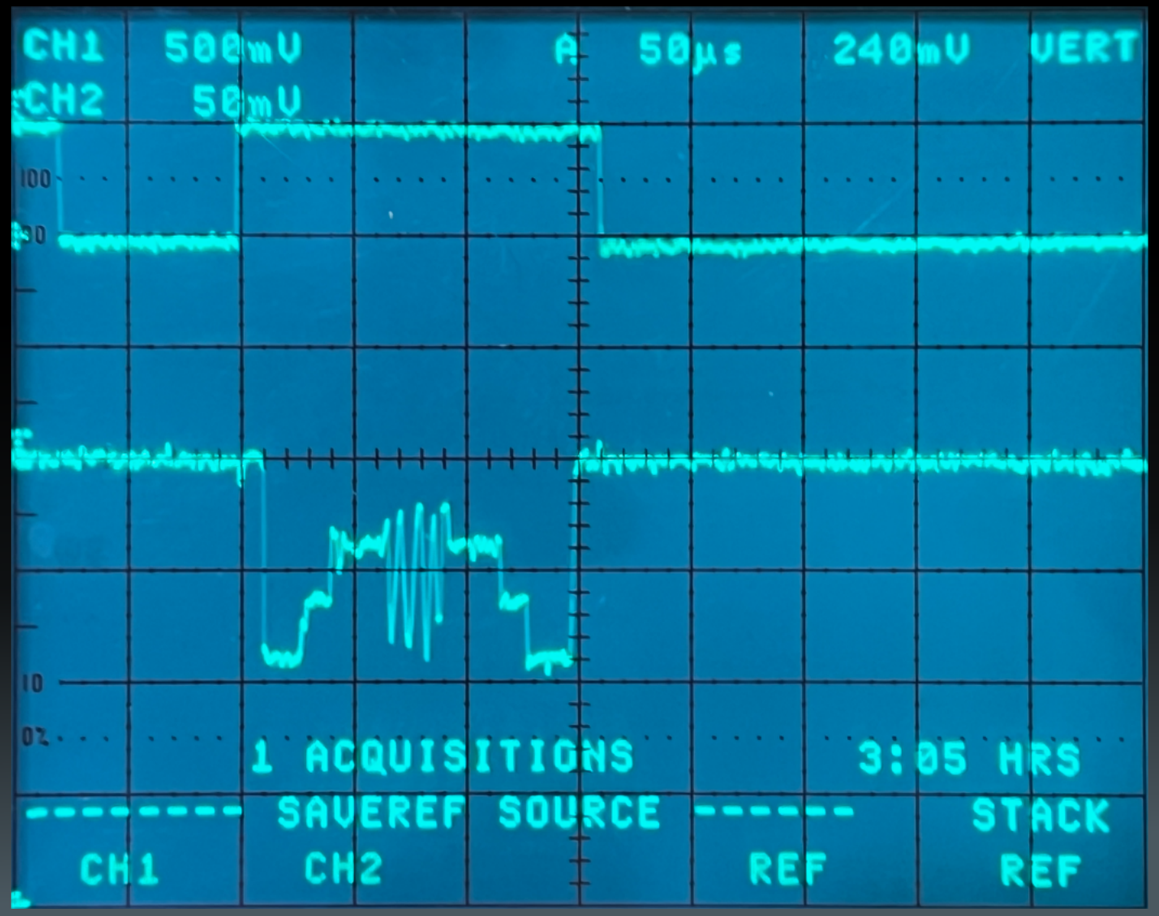
1. Carefully reassemble all (few hours);
2. On billion checks;
3. 3, 2… 1, switch on! Incredible, it WORKS!

❶ The exact measure of the shorter pins.
❷ The broken coax jumper (below) and the rebuilt one.
❸ Back to life! The old 7904 is the first one that I bought (for twenty euros), and shows again its bright and crisp traces.









7000 Series

Readout System

The today-obvious idea of displaying information on the oscilloscope screen was, in 1969, absolutely innovative, and was one of the amazing key points of the 7000-Series project. Here an rather detailed description and suggestion on its repair.

Readout System

Recently, I decided to have a better look to the 7000-Series readout system, and, in consequence, I could understand that definitely I didn't describe it in my books as it deserved. Probably, it is one of the more genial and innovative solution that I could see in my little activity related to ancient equipment; an LSD dreamlike delirium with an incredible mix of analog and digital technologies.

It seems cumbersome, I admit, and today it is very easy to say that they could have found an easier solution, but we must go back to the end of the sixties, when only few SSI ICs were available, and microprocessors were far from arriving.

Displaying data

The today-obvious idea of displaying information on the oscilloscope screen was, at the time, absolutely innovative, and was one of the amazing key points of the 7000-Series project. Earlier solutions had included fiber-optical/mechanical displays to the side of the CRT, or separate displays.

The design idea ultimately selected for the 7000-Series was proposed and designed by Barrie Gilbert, a true genius, and it used the CRT beam to display annotations in the same focal plane as the scope's main display.

How does it work?

Understanding the inner mechanisms of this complex clock is not easy, and the available information is even too detailed and so not easy to be penetrated, at least for me. So, we will try here to realize and explain it in its basic principles.

To do that, we have available the following documents: [1] the manuals; [2] the US patent number 3,651,510; [3] TekWiki. After having written this part, I discovered on TekWiki another precious documents [4] "Introduction to the 7000-Series scale factor readout system" (company confidential), by Ken Parker, November 1969, which would have saved me a lot of effort, if I had noticed it.



Most of the ICs on the mainframe readout board are Tektronix custom.

Character generation

The base element of the readout system is the **character generator IC**. In each scope, there are five of them: the limited integration capability of the time allowed to put only 10 character in every chip, but their operation is similar. In my opinion, the character generator is one of the most genial part of the whole system (but, as we are going to see, it is not alone). To understand it, I had to look at the patent document.

How to drive the beam?

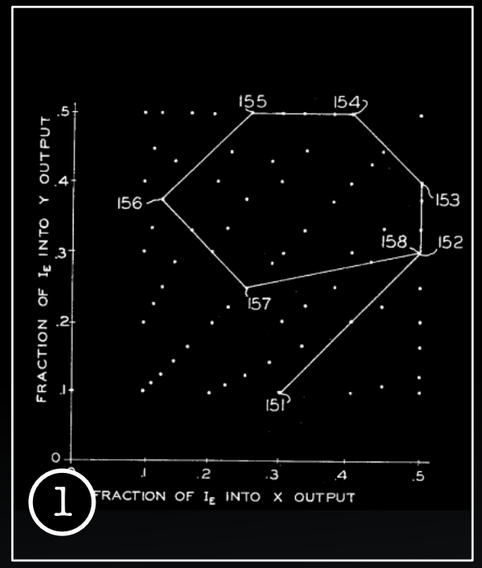
The character generator's purpose is to drive the CRT beam so that it depicts the desired character. See for example the number "9" (figure ❶). We must drive the beam in sequence from the point 151 to the 158. These point are in some way stored in a memory, capable of giving out the X and Y information for each of the points. Each character is made up of seven contiguous strokes connecting eight coordinate points.

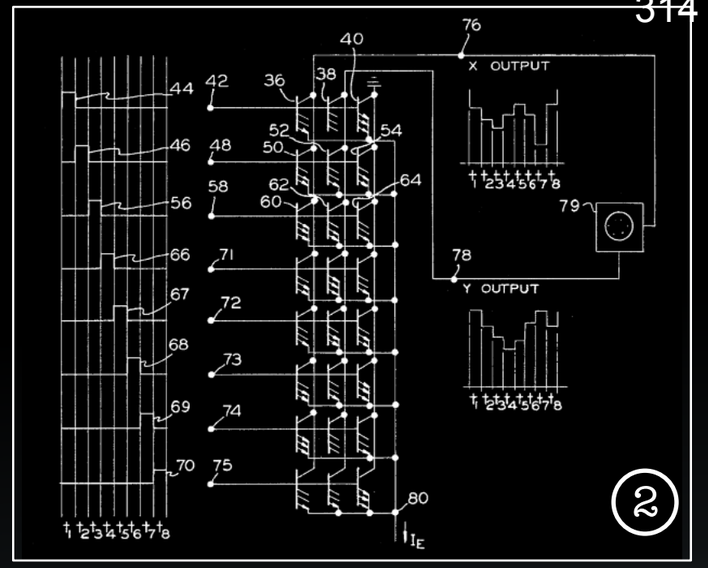
Storing the points

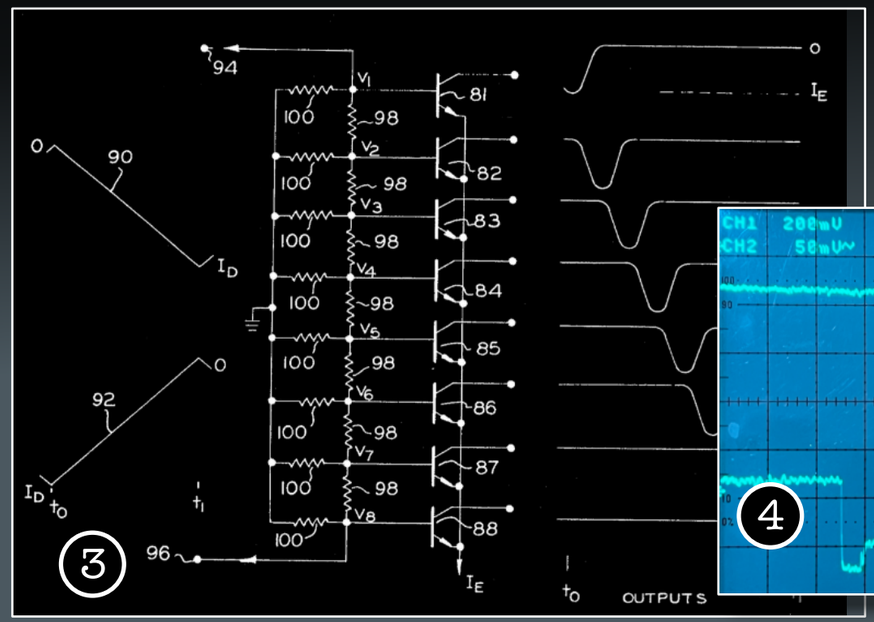
To reach this purpose, Barrie invented an analog memory chip based on the number of emitters of a transistor: the more the emitters number, the higher is the transistor current, and so the beam deflection (note: the third transistor in each trio merely serves as a drain for the excess unneeded current [4]). Figure ❷ shows the base principle of this circuit. Each group of transistors produces an X and an Y current pair. If you activate the transistors' bases in sequence, you can drive the CRT beam as the information stored in the emitters' number. Elementary, Watson.

Sequencing the points

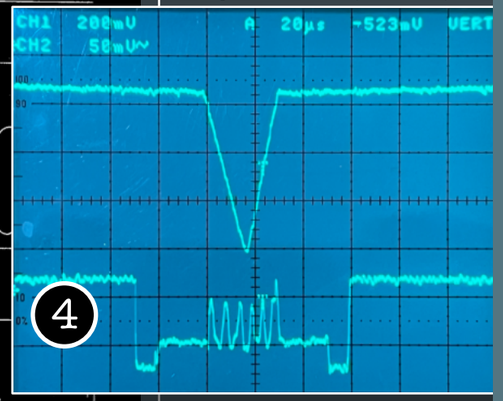
To drive the bases, today we would have used a sequencing digital circuit, that I have searched in vain. Here again a Gilbert's stroke of genius: to drive them in sequence just with a single electric pulse. Since abrupt sequencing would display points and not lines, it is necessary to gradually reduce the voltage on one trio of bases while increasing it on the next to produce smooth strokes. Such an action can be produced by using a special ladder network and a scanning voltage, as shown in figure ❸. Each transistor base circuit has different resistors' values and activates at a different input value. So, with just a simple triangle pulse, the beam runs forth and back across all the subsequent points of a character as we wished (the real circuit is somehow more complex than this but not too much) .







❶ A character is a sequence of points, joined by a segment, drawn by the CRT beam. ❷ The current is determined by the number of emitters. ❸ Each transistor is activated at a different level of the character scan pulse. ❹ The real character scan pulse and the Y output of U2270 (numerals).



The real IC

As noted, one chip contains ten of such circuits, each with different emitters combinations, and can thus generate ten different characters, with one enable pin for each of them (called column), while another enable line (called row) allows to select which character generator chip, out of five, is selected. In this approach, the emitter area itself is not varied in the mask, but out of a fixed number of emitters of equal size, a certain number is connected on each transistor. This allowed all character generator ICs to be manufactured with the same silicon layout, differing only in the metallization layers.

The circuit

In figure ❺ you can see the character generator circuit, that at this point, is straightforward. We have only:

- the five chips; for each of them, the contained characters are reported on the drawing;
- each chip has a "row" chip enable input (pin 9);
- each chip has ten "column" input, which allows to select the corresponding character;
- the X and Y output lines;
- the character scan input (pin 7), with the pulse that produces the movement of the beam.

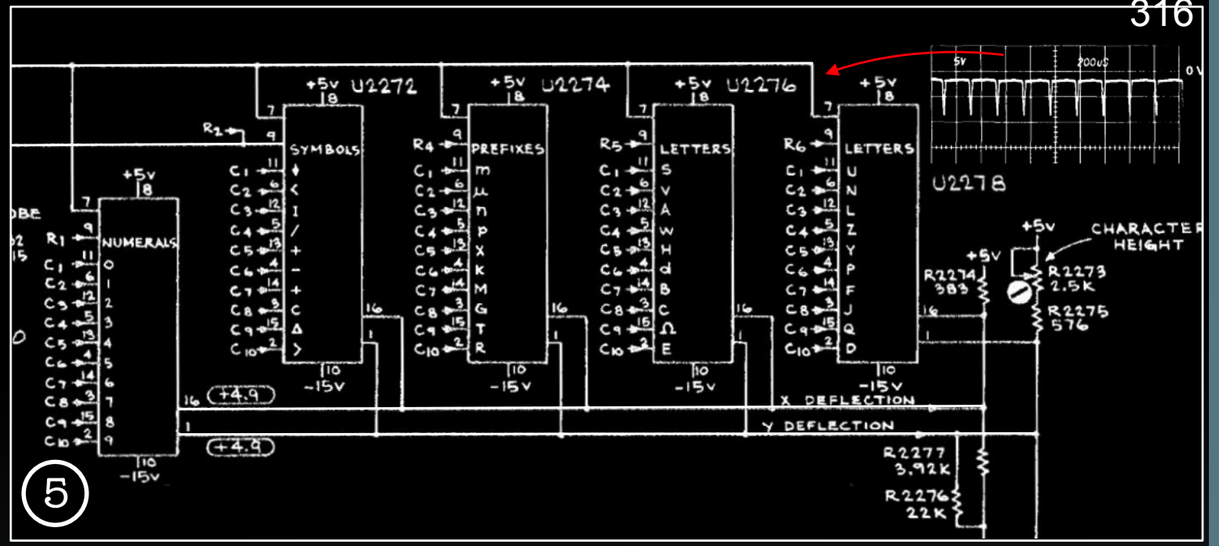
Display organisation

Now that we have the complete circuit that can produce and position the characters, how can these positions be filled with information?

The X and Y output currents are led to the FORMAT GENERATOR chip (U2284), that sums to them the CHANNEL COUNTER currents, positioning the writing in the proper area of the screen, and the CHARACTER POSITION (U2260), that position the single character of the string, before going to the CRT.

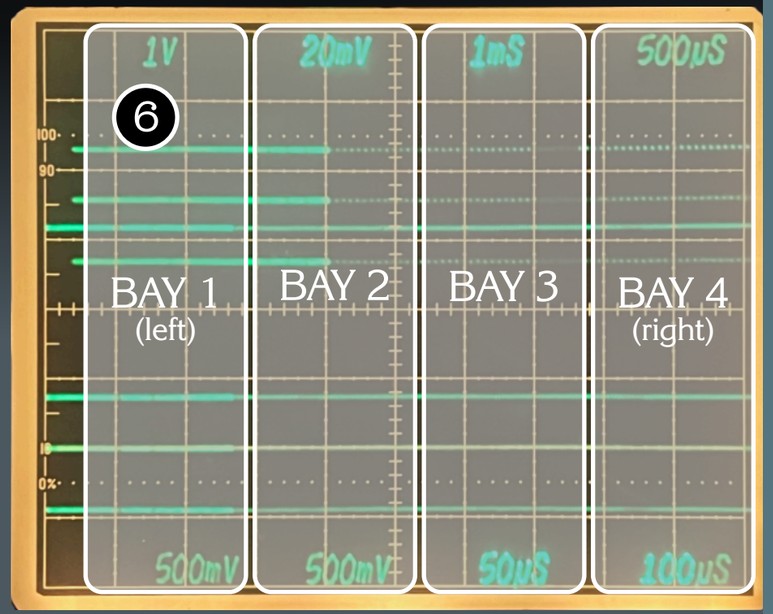
There are eight fixed positions (six in three-bay scopes) for text on the screen (figure ❻), each ten characters long. In correspondence with the bay, each plug-in has two positions available, one in the top part of the screen and one on the bottom part.

One of the Gilbert's solution advantages, is that it is really very, very simple from the point of view of the plug-ins, to produce the contents for the display. If the text to show is almost static, only few resistors are required on the plug-in side, obviously together with the switch to select them and perhaps few diodes.



Interrogations and answers

Interrogation. There are 10 Time-Slot pins on the plug-in connector (TS-1…TS-10). TS-1 pin receives from the mainframe a -15V pulse that asks the plug-in "which character do you want to display in position 1 of your first field?". Then is the turn of TS-2: "which character do you want to display in posi-



❺ The character generator's circuit. The row signal enables one of the character generator chips, while the column signal choose the specific character among those contained in the chip. The outputs X and Y drive the CRT beam when the character scan signal (pointed by the red arrow) is produced.
❻ The CRT screen of a four bay oscilloscope. Each plug-in has its reserved strings, one at the top and one at the bottom of the screen.

tion 2?" etc. Every TS-n pin asks for a character by sending its negative pulse, in sequence from TS-1 to TS-10.

Answering. If the question is in the end just a single pulse, answering is more complicated, because we must address which of the possible 50 character we want, plus some special function.

The solution is again very peculiar and genial. Each plug-in has available four pins to reply, a pair to write in the top position of the CRT, and a pair for the bottom position (eg. CH1 on top, CH2 on bottom). Let's talk only about CH1 only, CH2 is identical.

To answer the question, the plug-in channel 1 must connect each interrogating pin with these two pins by mean of two resistors, thus producing a pair of currents for each TS-1, TS-2…TS-n. One of these currents is called "column" and the other "row"

Each current value stays for a number from 0 to 10, according the current encoding table here on the right. The column current identifies the table column (so we understand the name "column"), and the row current the table row. For example, row=1 and column=2 identify the character "1".

In the reality, each Time-Slot does not correspond necessarily to a character and must follow some rules, as listed in the table ❾ on the next page. This table is not fixed for every possible plug-in. The table ❿ is for example related to the 7D13 plug-in, the electronic VOM, which can produce a volt, ampere or ohm value in its upper field on the CRT.

Decoding the answers

Now we have from one side the interrogation/answering system and from the other the character display system. Each character is interrogated separately for each screen position, so now we must only link the answers (current pairs) to the right character. This again is simple and genial.

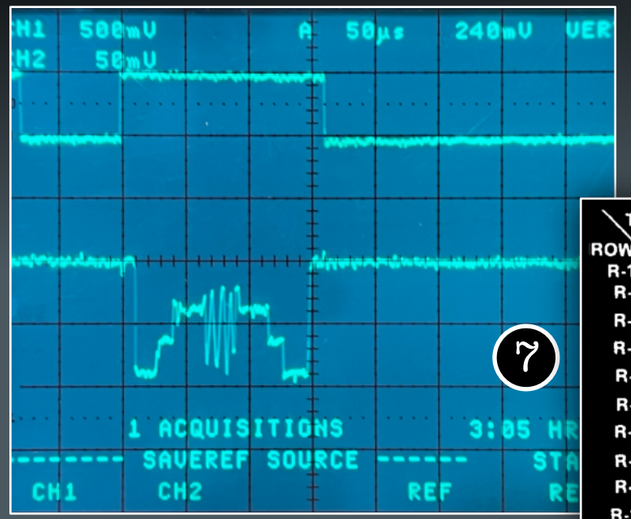
TS-n signals are global and go to all the plug-ins. Thus, all the plug-ins reply at the same time: in fact, we have 8 lines for the rows and 8 for the columns; but only one answer (couple of currents) is processed at a time.

The right lines pair is selected by U2250 CHANNEL COUNTER (7493), with the aid of the COLUMN and ROW DATA SWITCHes, U2190 and U2180 (both 155-0015 custom ICs).

At the next cycle, the CHANNEL COUNTER will be incremented and the next channel is processed.

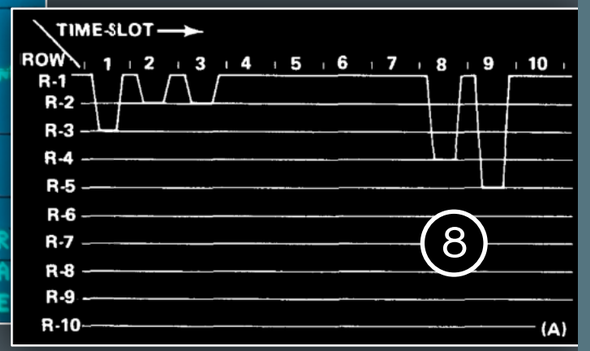
ROW NUMBER \ COLUMN NUMBER →	CURRENT (MILLI-AMPERES)	C-0	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10
		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	> 1.0
R-1	0	SKIP[1]	0	1	2	3	4	5	6	7	8	9
R-2	0.1		↓	<	I	/	+	–	+	C	Δ	>
R-3	0.2		ADD[1] ONE ZERO	ADD[1] TWO ZEROS	SHIFT[1] PREFIX ←	SHIFT[1] PREFIX ← AND ADD ONE ZERO						IDENTIFY[1]
R-4	0.3		m	μ	n	p	X	K	M	G	T	R
R-5	0.4		S	V	A	W	H	d	B	c	Ω	E
R-6	0.5		U	N	L	Z	Y	P	F	J	Q	D
R-7	0.6				DECIMAL[1] POINT LOCATION NO. 3	DECIMAL[1] POINT LOCATION NO. 4	DECIMAL[1] POINT LOCATION NO. 5	DECIMAL[1] POINT LOCATION NO. 6	DECIMAL[1] POINT LOCATION NO. 7			
R-8	0.7										DECIMAL[2] POINT	
R-9	0.8											
R-10	0.9	ADD SPACE IN DISPLAY[1]										

6



7

❼ The character selection matrix as a function of current values. Some positions contains command and not viewable characters. ❽ Upper trace: the R4 signal (row) Lowe trace: the Y output of U2270 chip (numerals). Note that the pulse is symmetric, that means that the character is run across two times, forth and back. ❽ The row pulses sequence for the string "↓100µV". A corresponding diagram is produced for the column pulses.



8

The selected currents are then decoded by mean of specialized analog to digital converters: U2244 for columns and U2185 for rows (both 155-0014 custom ICs), that produce the individual column signals C1…C10 and row signals R1…R10, that go directly to the character generators.

Useful definitions

Character A single number, letter, or symbol displayed on the CRT, either alone or in combination with other characters.

Word Made up of a group of related characters. In the Readout System, a word can consist of up to 10 characters.

Frame A display of all words for a given operating mode and plug-in combination. Up to 8 words can be displayed in one frame. Figure 3-24 shows the position of each word in a complete frame.Column--One of the vertical lines in the Character Selection Matrix (see Fig. 3-25). Columns C-0 (column zero) to C-10 (column 10) can be addressed by the system.

Row -One of the horizontal lines in the Character Selection Matrix. Rows R-1 (row 1) through R-10 (row 10) and R-14 (row 14) can be addressed by the system.

Time-Slot A location in a pulse train. In the Readout System, the pulse train consists of 10 negative-going pulses. Each time-slot pulse is assigned a number between 1 and 10. For example, the first time-slot is TS-1.

Time-Multiplexing Transmission of data from two or more sources over a common path by using different time intervals for different signals.

The Cn signals go directly to all the chips, while the Rn signals are used to select the proper chip among the five that all together contains the complete symbol set.

Sequencing

All the system is sequenced by the U2126 TIMER custom IC (155-0021), that produces mainly:

- the timing waveforms used by most of the other circuits (pin 6, 10 and 5, TRIGGER signal);
- the CHARACTER SCAN signal that we already know (pin 6);
- the signal required to stop the mainframe normal operation and display the readout (Z-AXIS LOGIC OFF command (pin 14), the VERTICAL and HORIZONTAL OFF command (pin 13), the READOUT INTENSITY signal (pin 12).

The real circuit

Eventually, things could seem rather simple, but the real circuit is more complex, fundamentally for two reasons:

- the above said sequencing logic, however by itself rather easy to understand now;
- some special useful functions, that we are going to describe.

Standard Readout Format

Time-Slot Number	Description
TS-1	Determines decimal magnitude (number of zeros displayed or prefix change information) or the IDENTIFY function (no display during this time-slot).
TS-2	Indicates normal or inverted input (no display for normal).
TS-3	Indicates calibrated or uncalibrated condition of plug-in variable control (no display for calibrated condition).
TS-4	1-2-5 scaling.
TS-5 TS-6 TS-7	Not encoded by plug-in unit. Left blank to allow addition of zeros by Readout System.
TS-8	Defines the prefix which modifies the units of measurement.
TS-9 TS-10	Define the units of measurement of the plug-in unit. May be standard units of measurement (V, A, S, etc.,) or special units selected from the Character Selection Matrix.

❾

7D13 READOUT FORMAT

TIME-SLOT NUMBER	DESCRIPTION
TS-1	Determines decimal position. Also, encodes a JUMP instruction to indicate over-ranging.
TS-2	Not used
TS-3	Indicates polarity of measurement.
TS-4	Most significant digit of measurement readout.
TS-5, TS-6 TS-7	Remaining three digits of measurement readout.
TS-8	Encodes m (milli-) and k (kilo-) prefixes, V (volts) and C (Celsius) measurement units.
TS-9	Encodes A (amperes) and Ω (ohms) measurement units.
TS-10	Not used

❿

❾ The standard Time-Slots table. As you can see, some TS has special use and does not produce a character on the screen. This table is good for the most common plug-ins, like 7A18, 7A26, 7B70, 7B53A etc.

❿ Digital plug-ins may have their own use of the Time-Slot. Here we can see the 7D13, a digital volt/ohm-meter, that needs to show longer strings.

Special characters

Some positions in the matrix have special meaning to make more efficient the dialog; for example, row=3, column=2 in the first position is a command that says “add two zeroes to the following number”. In other words, the primary function of the row and column outputs is to select a character from the Character Selection Matrix to be produced by the Character Generator stage but these outputs are also used at other points within the system to indicate when certain information has been encoded.

One such stage is the ZEROS LOGIC & MEMORY chip U2232 (155-0018) . During Time-Slot 1 (TS-1), this stage checks if zero-adding or prefix-shifting information has been encoded by the plug-in unit, and stores it in the memory until Time-Slots 5, 6, or 8. After storing this information, it triggers the Display-Skip Generator stage (Q2215, Q2223, Q2229) so that there is no display during Time-Slot 1 . When Time-Slots 5, 6, and 8 occur, the memory is addressed and any information stored there during Time-Slot 1 is transferred to the input of the COLUMN DECODER stage to modify the analog data during the applicable time-slot.

Note also the SKIP command: if the plug-in has no resistor on the zero column, its current is null and the state is skipped, producing the shortening of the cycle from 250 to 210µs, but, above all, avoiding to interrupt the signal trace for the readout.

TS	R	C	Meaning
TS-1	3	2	Add two zeroes
TS-2	2	1	“-”
TS-3	2	10	‘>’
TS-4	1	2	‘1’
TS-5			Not used
TS-6			Not used
TS-7			Not used
TS-8	4	2	‘µ’
TS-9	5	2	‘V’
TS-10			Not used

Probes

As many know, the 7000-Series readout system is capable to identify the x10 probes and correct the display information. For example, if you set the knob on .5V/div, the readout should indicate 5V/div, when you use a x10 probe. That is done by inserting a fixed resistor between the ring that surrounds the BNC input connector. Its value is less known: it must be 10 or 11kOhm. That also was an important innovation, which has come down to the present day; maybe that it is not only in my experience, having done mistakes due to the wrong consideration of the probe factors. Some relatively modern oscilloscope, like the luxury HP 54540A, that you find described in this book, requires to manually set the probe factor.

The IDENTIFY function

Each channel has normally a button to identify the corresponding trace on the screen. When you press it, the string IDENTIFY is produced in the readout field on the CRT. Where comes that string from?

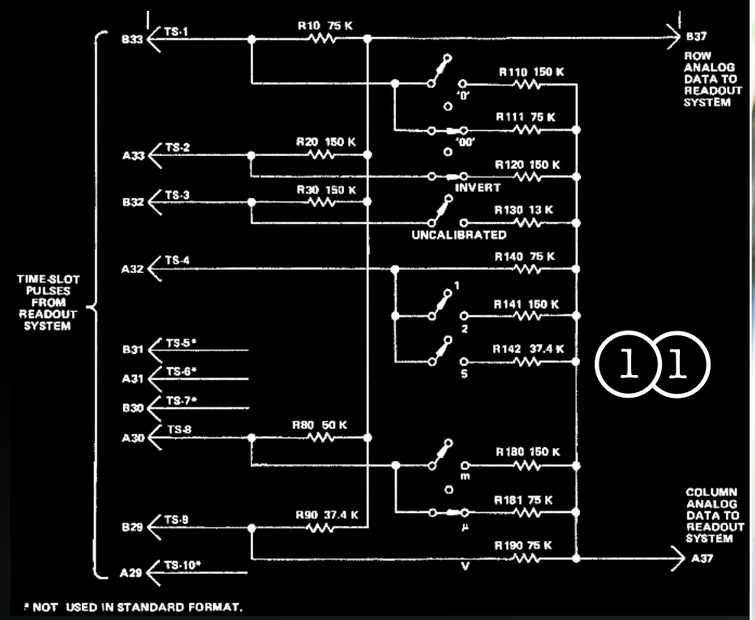
The ZEROS LOGIC & MEMORY chip U2232 produces the IDENTIFY function. When time-slot 1 is encoded for IDENTIFY (column 10, row 3), this stage produces an output level, which connects the U2191 COLUMN DATA SWITCH and U2232 ROW DATA SWITCH to a coding network. Then, during time-slots 2 through 9, an analog current output is produced from the COLUMN DATA SWITCH and ROW DATA SWITCH which addresses the correct points in the Character Selection Matrix to display the word "IDENTIFY" on the CRT.

An example

I report here an example taken from TekWiki. Look at the above circuit: it could be the logic on a vertical amplifier plug-in, like the 7A18 and let’s try to guess what string will appear on the screen.

With all the information we gave here, it’s rather easy: the string is “ ↓100µV”as shown by the table in the front page on the left.

In the this other table on the right, the resistor required to obtain the various current values (the reference voltage is exactly 15V).



Repairs

I've only fixed two boards so far, and both had the same IC faulty: one of the two 155-0015, that completely canceled the readout.

Determining which chip or transistor is the wrong one is not a trivial task, but now that you have understood most of the inner mechanisms of the board, it should be much easier.

I prefer however the “coward approach”. I use a good readout board, and I replace one by one the chips from the faulty board, until I find the wrong one.

I (mA)	R	R meaning	C meaning
0	∞	1	0
0.1	150k	2	1
0.2	75k	3	2
0.3	50k	4	3
0.4	37.5k	5	4
0.5	30k	6	5
0.6	25k	7	6
0.7	21.5k	8	7
0.8	18.75k	9	8
0.9	16.6k	10	9
>1	13k	Not allowed	10



The 7A18 rotary cam switches that composes the readout interface together with few passive components.

Summing up

The ❶❸ diagram on the front page resumes most of the concepts that we have quickly described above.

A successful story

This wonderful circuit has been used in many products, like the 7603, 7623A, 7633, 7904, 7844 described in this book. Conversely, it is not used in the 7854 which contains a complete microprocessor system, with its own display system, more conventional from today's point of view, capable of producing 16 line of 40 character each.

A real triumph for the Barrie Gilbert project. The circuit was relatively inexpensive and very reliable, as still today we can confirm. The limitations that I could observe are few and not terrible:

- the readout is a time-sharing system, and so you can notice random gaps in the traces due to blanking intervals;
- the characters cannot include separate segments, e.g. ":"or "!";
- the "8" character is rather ugly.

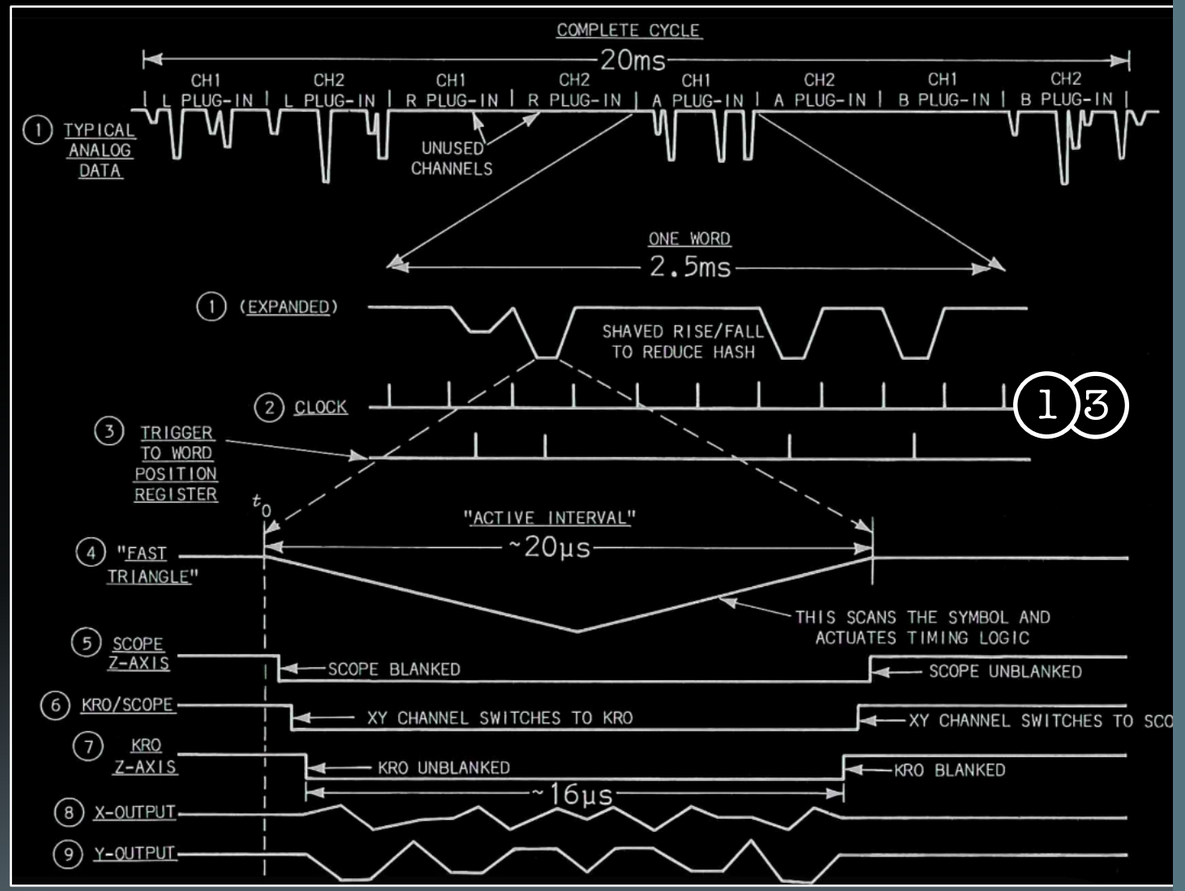
The end

Towards the end of the 7000-Series lifespan, in the second half of the 1980s, a re-designed readout board was introduced, in which the character generator is based on digital values stored in a 2732 EPROM instead of Gilbert's analog ROMs, with the number of display points increased to up to 16 per character. A similar design has been adopted in the 2465 series.

Finally, from 1989/1990 on, a third generation readout board designed around an 80C31 micro-controller replaced the previous versions in the last series of 7104, R7103, R7844, 7904A, 7603 and 7623B models. This version no longer used any Tek-made special ICs, manufacture of which had been discontinued by that time [most of this information comes from TekWiki].

We can conclude that the original readout system was really well designed, if a 1968 design could survive for so long, despite the more modern technologies available since the mid-seventies.

Never change a winning team.

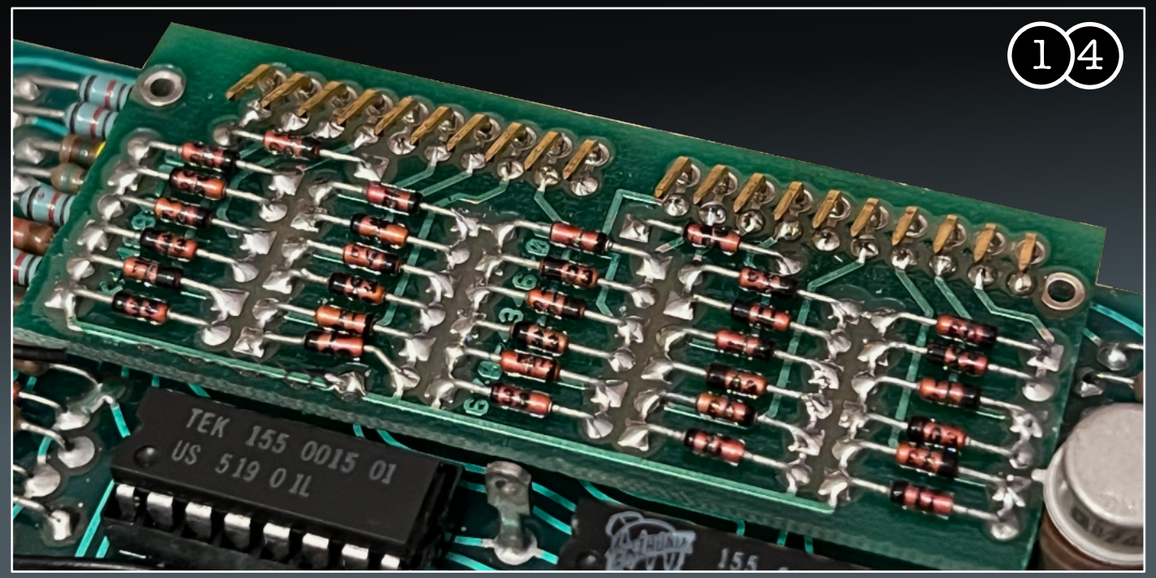


Readout Board Map and Conns

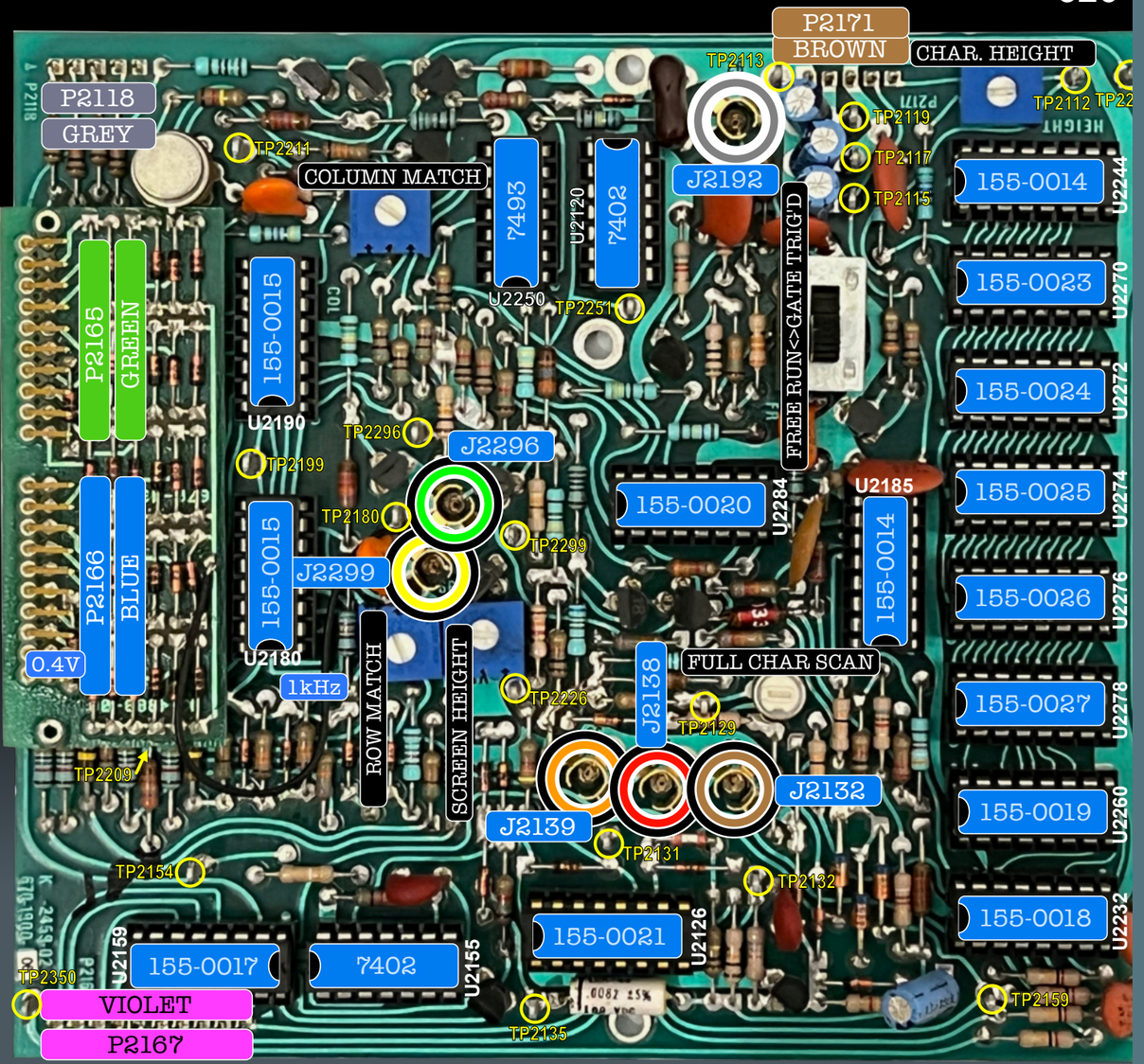
The 155-0015 are probably the most exposed to damaging actions, because they constitute the interface with the plug-ins, so they can more easily get, for example, static discharges. For this reason, Tektronix added subsequently a protection board (photo ❶❹), with many diodes on it, as shown in the photo.

You can try to remove, alternatively, one of the 155-0015. If just one of them is defective, the display will reappear, even if with confused characters (the column or the row information is missing).

In the front page, a map (❶❺) of the readout board; I hope it can help you like it helped me if you need a reparation. The colored circles identify the corresponding coaxial cables to be put in those connectors.



❶❹



❶❺



7000 Series

CRT Storage

The power supply of the best 7000-Series, 4 slots, oscilloscopes is the black beast of the restorers. Its intelligent design makes it extremely robust, thanks to many self-protection mechanisms, which, when triggered, produces the typical “click” sound. Here you can find an in-depth analysis which can help you considerably when repairing them or to understand which external cause might determine it.



Subsection: Calibration

Calibrating a CRT Storage Oscilloscope is rather complex. Here we take as an example the 7834, but the notes apply almost to all the 7000-Series Models

Fixing CRT Storage

Case study

I bought the 7834 knowing it was out of order, but I hoped I could repair it. As described elsewhere, I had to work on it quite a bit. Resuming, this is what I did:

- the HEPS was **clicking**; I checked and **recapped** the High Efficiency Power Supply, but the problem was not there. A recap is however always welcome;
- I found and changed changed a **shorted Tantalum capacitor** on the Readout Board, and with that it returned to life;
- after the first working hour, anyway, the HEPS returned to **click**. It was a complex battle, and you can find the whole repair story in this book (HEPS section). The problem was the **HV multiplier**, the one which produces the Post Deflection Acceleration voltage (8 kV). I was lucky: a friend from Tekscope IO.group supplied me the spare part, and so the 7834 started again to work;
- later, I discovered that the **cathode voltage was low** (1920 instead o 1950V). I had a long fight against this problem and only partially won, but finally the voltage was OK. This story also is contained in this book, again in the HEPS section.

After that, the 7834 worked perfectly in non-storage mode, but very, very badly in storage, with an almost ridiculous writing speed.

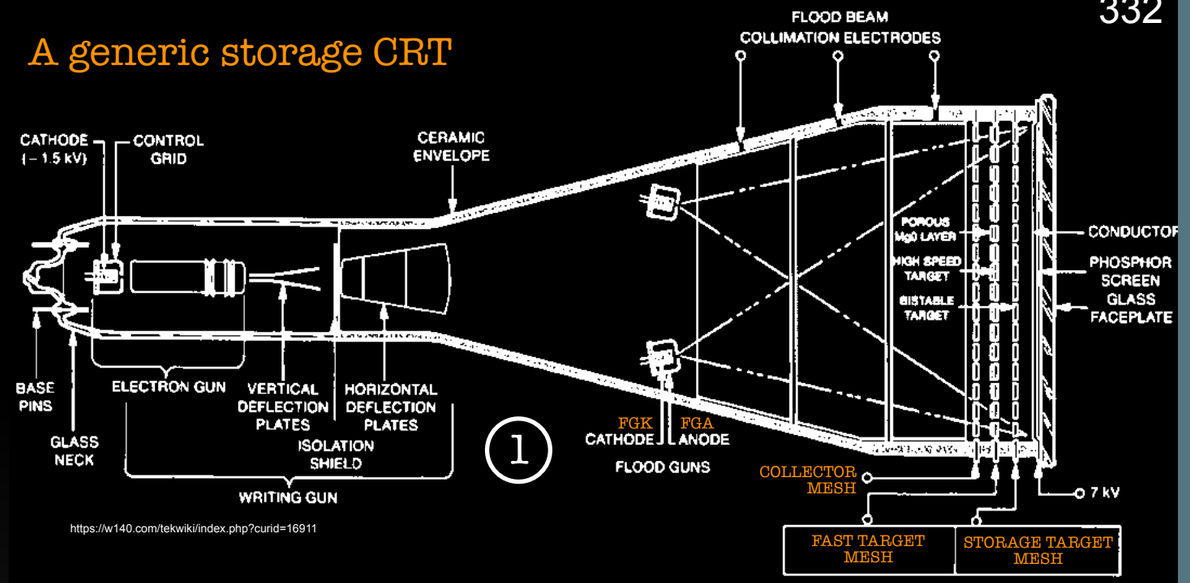
Investigation approach

Initially, I tried to mess up the various trimmers on the Storage Board, but I could only worsen the situation. So I decided to understand a little better how this intricate circuit works. As usual, I note here my experience, should you also need to repair yours storage oscilloscope, or simply because you are curious.

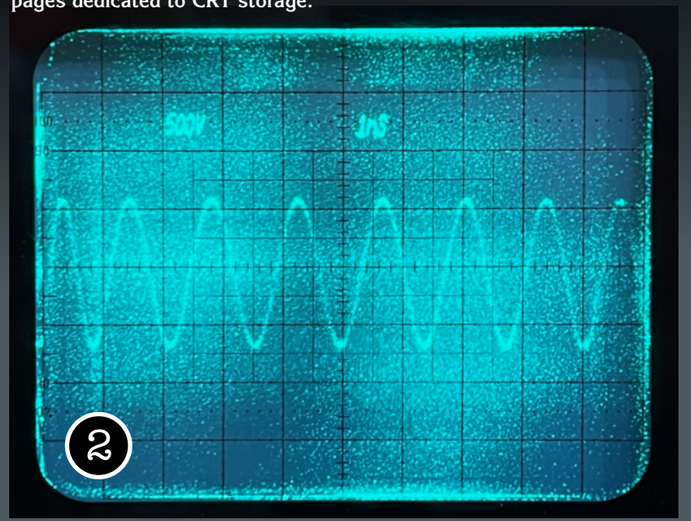
Apart from the few specific differences (e.g., the reduced scan, most of what follows is as well valid for the 7623A, the 7633 and probably for the 7613, the 7623, and the 7934.

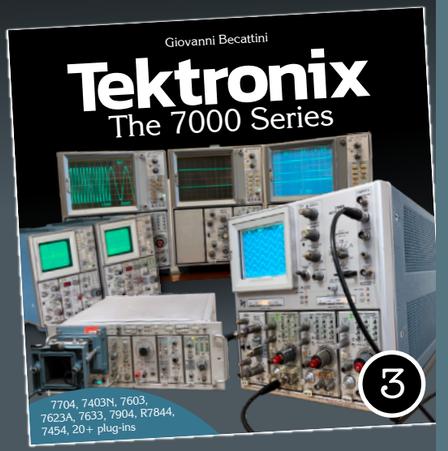
First of all, I suggest to read, if you didn't, the chapter on the CRT storage technology in my book about the 7000 Series.

A generic storage CRT



❶ A rather detailed schematic of a storage CRT. Apart from having only three collimator electrodes instead of four, it could be the 7834's one. ❷ A 350 MHz in reduced scan mode after a first calibration session, far beyond the official specifications. The quality is not exceptional, but the waveform is completely and well defined. The time base is a 7B85, so to scale to 1 ns it was necessary to use the horizontal x10 expander. ❸ My e-book about the 7000 Series has many pages dedicated to CRT storage.





The starting point

Tektronix' documentation is rather incomplete and not error-proof, so I will try first to put some order in the available information.

CRT electrodes

The picture on the previous page describes a generic storage tube. In it, I edited some electrode names (in orange) to reflect those used in the 7000-Series documentation. In addition to the standard signals of a normal oscilloscopes, a CRT storage scope requires to drive the following lines:

- FRONT MESH, i.e., the storage target (called also "bistable" target);
- FAST TARGET MESH, used in FAST modes;
- COLLECTOR MESH, to collect the electrons knocked-out by the writing beam;
- CE1, CE2, CE3, CE4, collimation electrodes;
- FGA, Flood Gun Accelerators (anodes);
- FGK, Flood Gun Cathodes.

A sequencer

The storage operation is controlled mainly by the Storage Board, named A25 in the 7834. The first difference we can observe from the 76xx models is that the control panel buttons are in a separate A24 board. From a logic point of view, we will consider A24 and A25 as a single unit, calling it the Storage Board, unless a distinction is necessary.

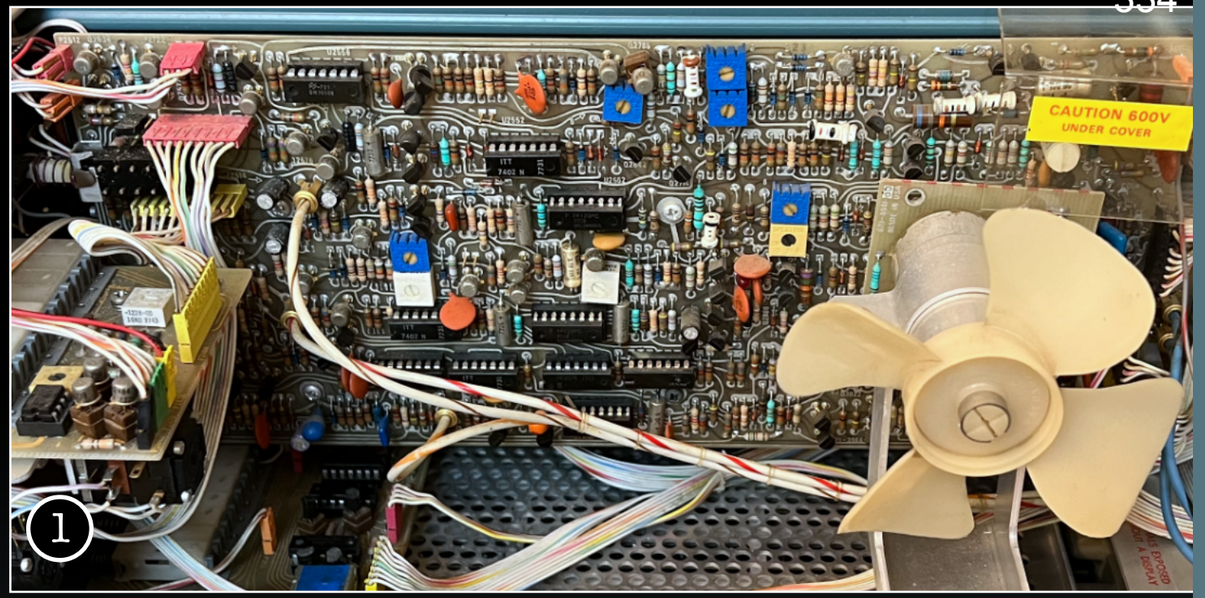
The Storage Board is just a sequencer; i.e., it is not a closed-loop controller, but just generate the signals required by the CRT in the proper order. For each signal, a suitable level translator is provided, to reach the voltage values required by the tube. Tektronix calls these circuits **operational amplifiers**.

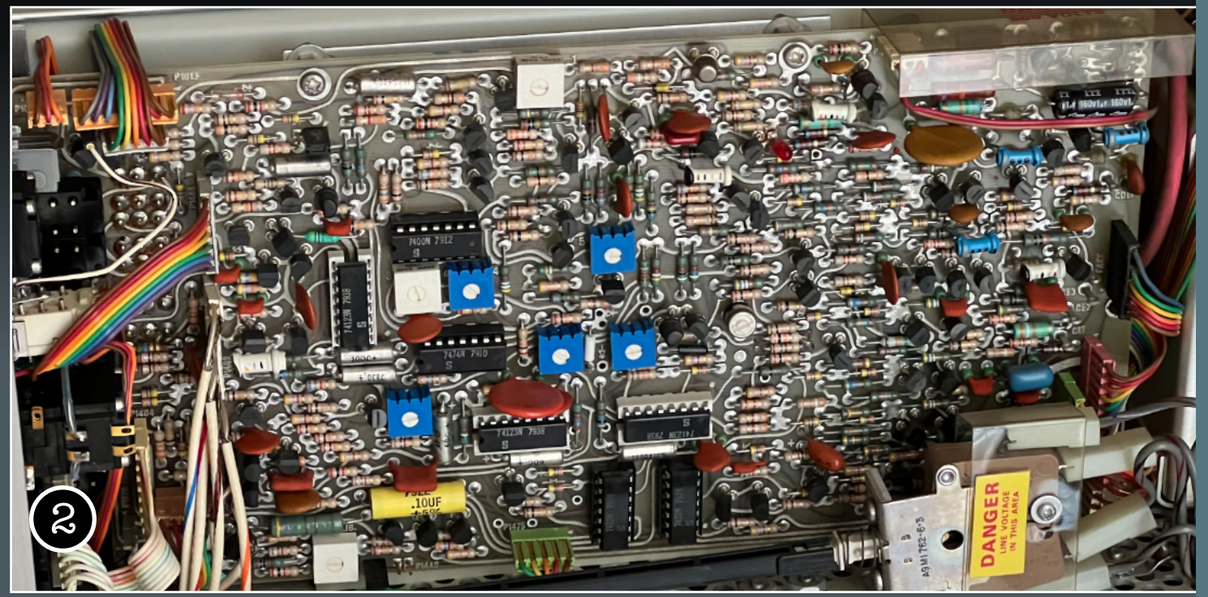
Abbreviations

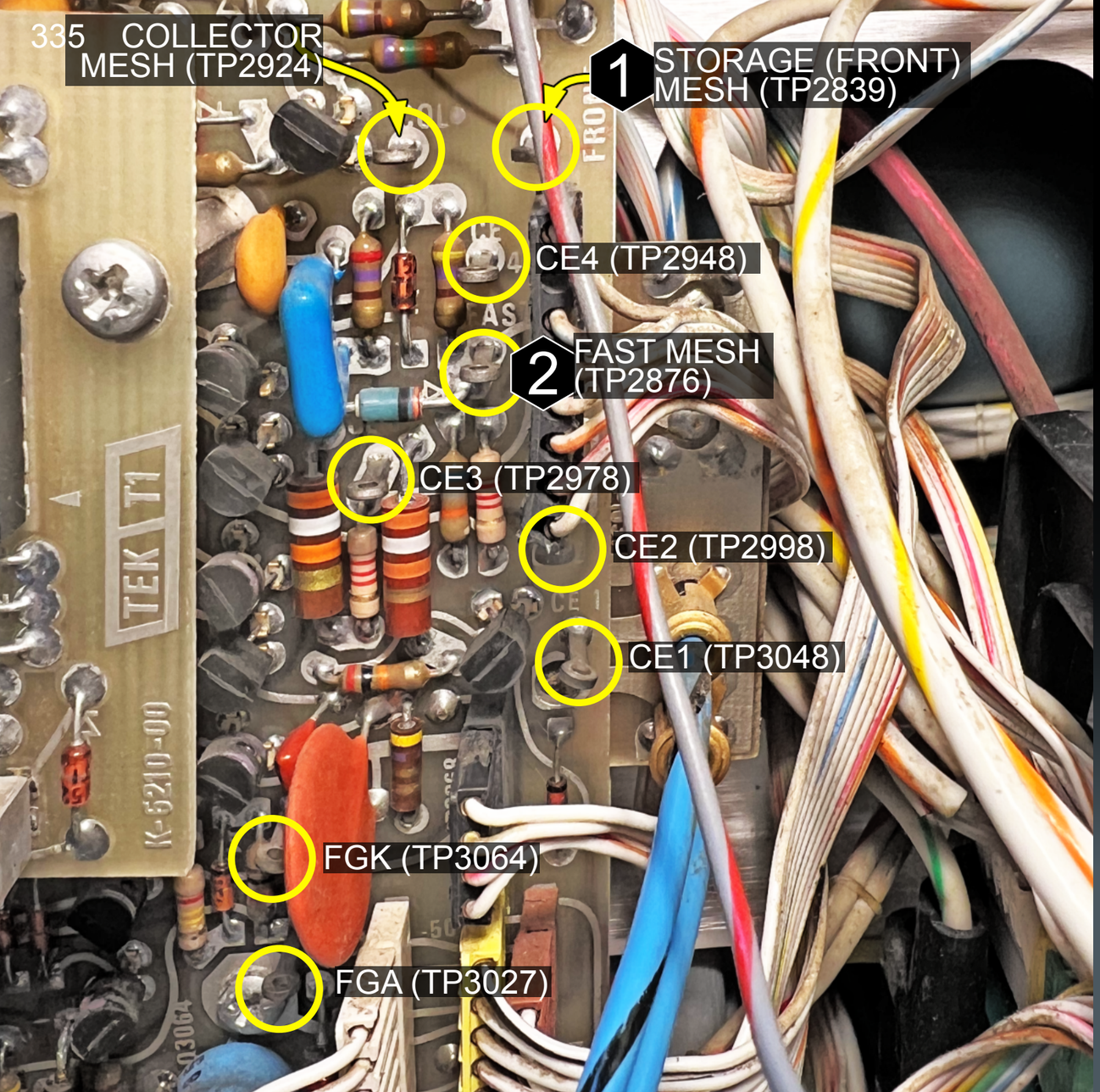
Maybe I am a little slow understanding, but their meanings were not immediately clear to me:

- BS = Bi-Stable;
- VP = Variable Persistence;
- FS = Full scan;
- RS = Reduced Scan.

❶ The Storage Board of the 7834, besides the funny and dangerous fan which is advisable to disconnect during the tests, is not identical to the 7823A one (❷), but reveals the same general architecture and technology. Probably in 1977 there were not long-term perspectives for designing a new microprocessor-based board.







Preliminary calibrations

Before affording the problems of the storage section, we need to be sure that the other CRT parameters are properly set. The manual is explicit on this point:

> *External and internal focus and astigmatism adjustments affect stored writing speed. If the stored writing speed specifications in the following procedure cannot be met, refer to the Z-Axis and Display procedure in this section.*
>
> *Also, optimum stored writing speed can only be obtained when actual operating voltages and waveforms are within the limits specified in the voltage and waveform conditions. The voltage and waveform conditions are located preceding the Storage Display schematic in the Diagrams section of this manual.*

I followed manual's instructions without big problems, and I found that my 7834 was almost perfectly tuned, even in power supply voltages. I omitted only the tests which required the 067-0587-01 text fixture, which I don't have, but only those related to CRT image geometry, that seems however good.

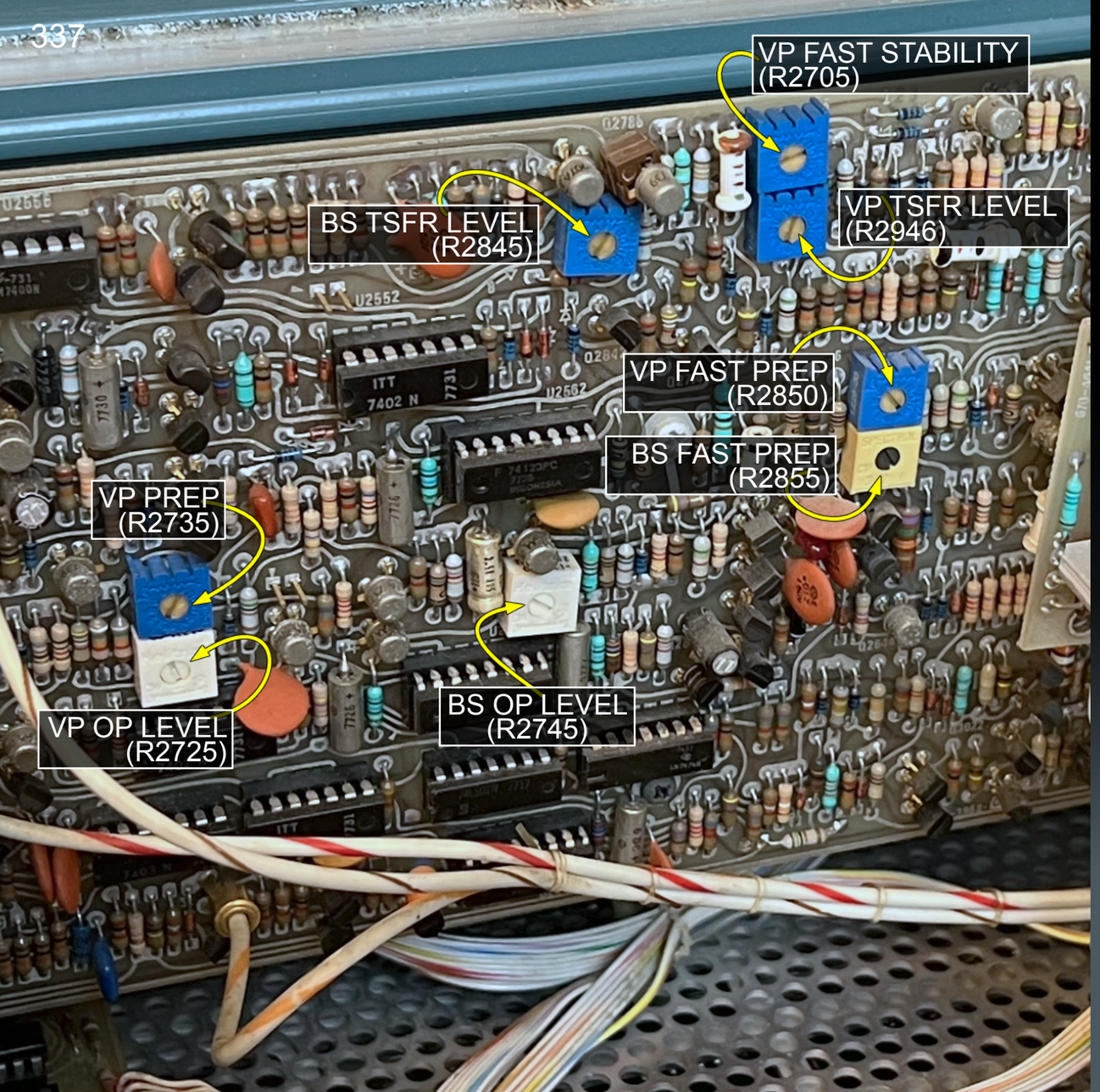
Test points & trimmers

The Storage Board provides a test point for each of the lines to the storage part of the CRT. The component layouts in the manuals are rather hard to read, so I decided to build a picture for them (on the opposite page) and for the adjustment trimmers (on the next page).

Preliminary voltages check

The manuals report, for each oscilloscope model, the expected static voltages in the schematic diagram section. Most of them have only two possible values. To allow you to test both with a simple voltmeter, they tell you to remove a transistor to check the non-quiescent state. I did, and I found that all the voltages were almost perfect. That was not a joy for me, because I am trying to investigate the bad storage operation of my scope. I checked also the reported waveforms without finding any anomaly.

On the left: the CRT test points for the storage functions.



The trimmers

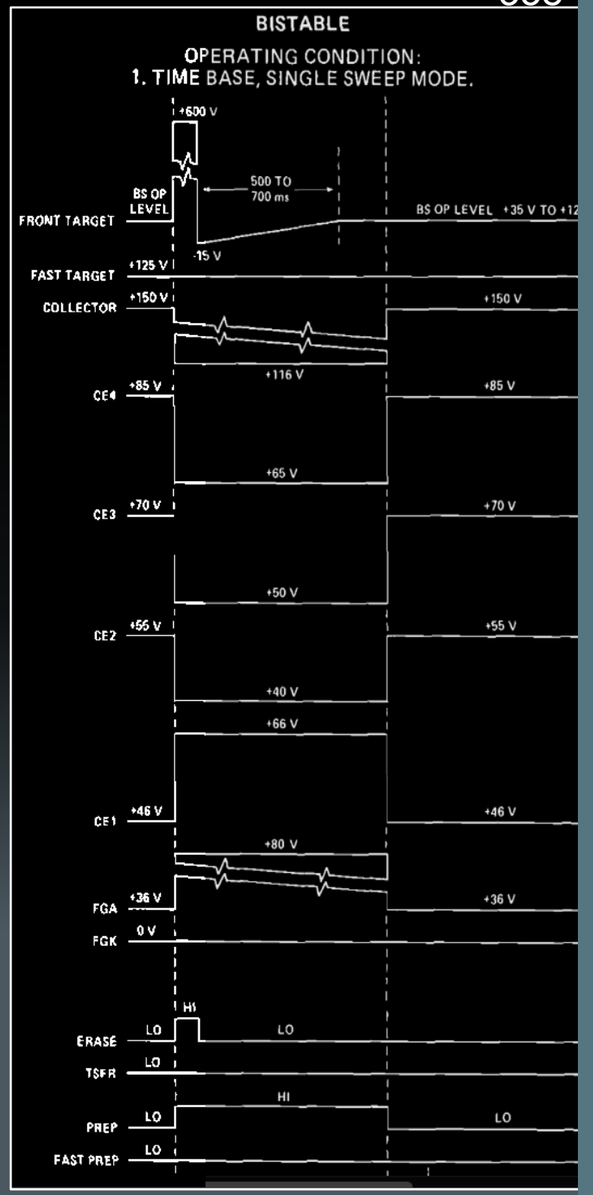
The Storage Board has eight resistive trimmers; their adjustment completely changes the scope's performance. Don't try to set them at a guess. You must follow the instructions reported on the manuals. Understanding them is not always easy, but with some effort we can succeed. The trimmers are:

- OP LEVEL for Bistable (R2745) and Variable Persistence (R2575);
- PREP for Bistable Fast (R2855), Variable Persistence (R2735), and Variable Persistence Fast (R2850);
- TRANSFER LEVEL for Bistable (R2845) and Variable Persistence (R2946);
- STABILITY for Variable Persistence (R2705).

The Bistable Mode

This is the easiest of all. To be honest, I started this calibration without faith, because it seemed to me that my efforts were worthless. That is in part due to my dumbness and to the ease with which mistakes can be made, also for the not exceptional clarity of the manuals. You must pay maximum care and, if no fault is present, you might be rewarded.

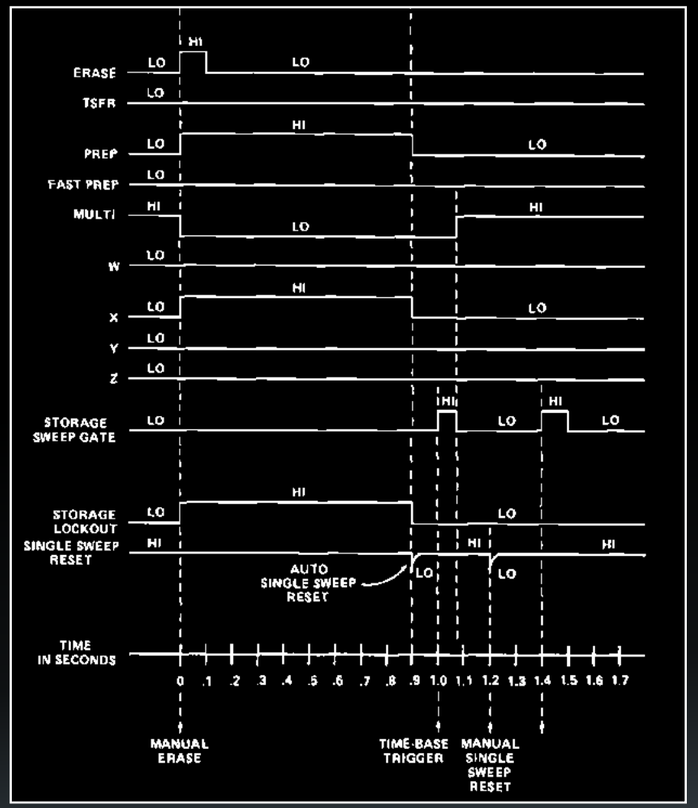
In a first moment, I thought to check the timing diagrams reported in the manuals (see for example here a portion of the Bistable one). In case of relevant faults it can be an help, but for the normal calibration it is not necessary. The timing is probably right and not very critical; the real problem, in my experience, is setting the trimmers, and to do that you must follow the manual and only the manual.



Satisfying BISTABLE curiosity

Even if, as I said, the calibration does not require we understand the complete timing, I tried to work with my phantasy at least to understand some basics of the storage cycle. The manual does not help very much, because it supplies several details but lacks a complete picture overview.

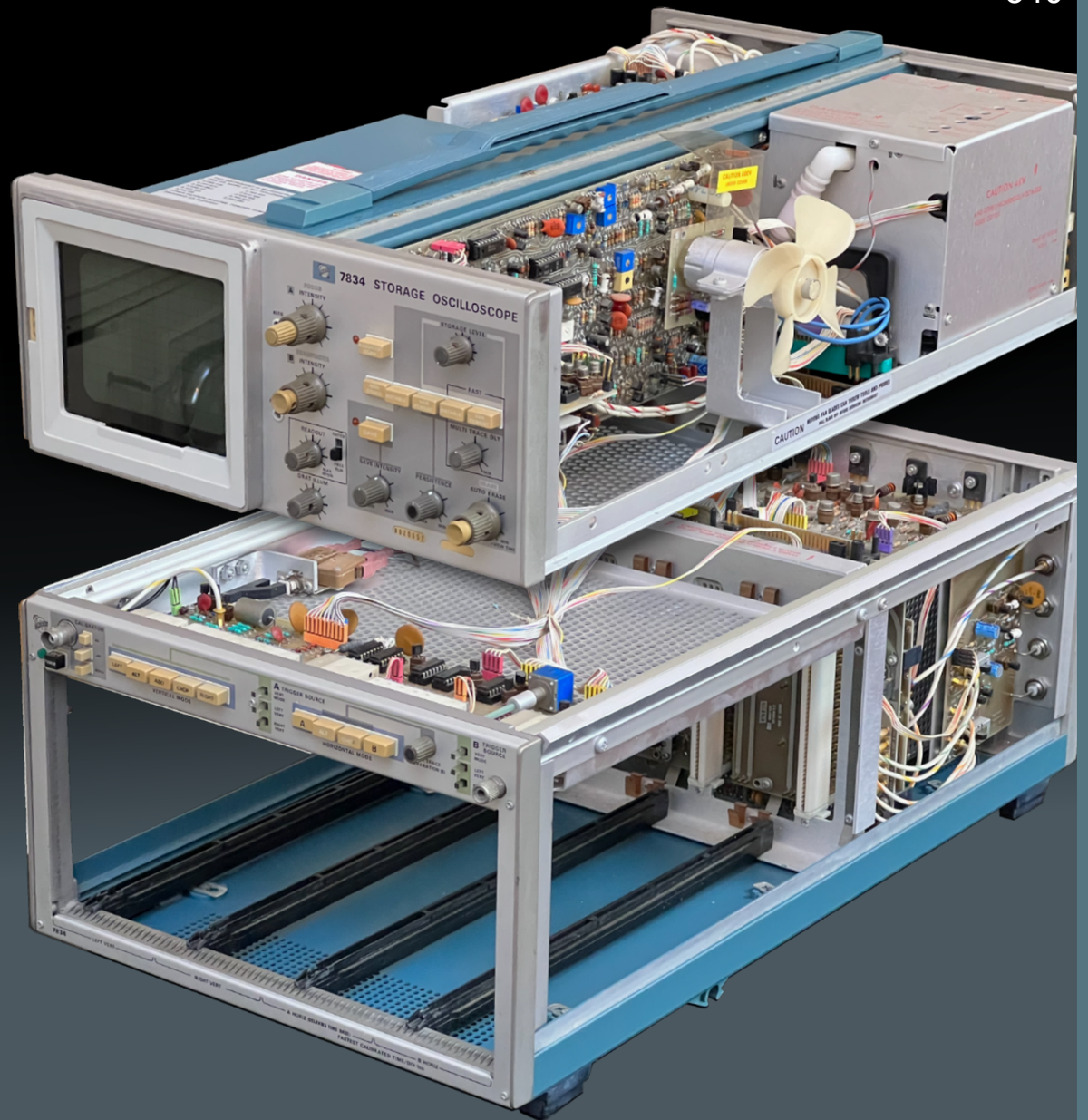
For this exercise, we need also the lower part of the timing diagram of the previous page.



Like a wax tablet

The storage system, by itself, does nothing "to store" a waveform; on the contrary, it just prepares the screen, so that a trace can be stored on it. It reminds the ancient Romans' **wax tablet**, ready to be written after an erase cycle. You can see this rather well from the diagram. There is an erase pulse, followed by a preparation cycle, during which the sweep is locked, as signaled by the STORAGE LOCKOUT signal. I don't know what all the electrode values are meant of; I just interpret them like a "recipe", which surely has its reasons.

When all is ready, the STORAGE LOCKOUT becomes invalid and a pulse is generated to reset the time base single sweep. When the time base is triggered, it asserts the STORAGE SWEEP GATE. The beam paints the trace on the screen, which is stored and made visible. From this point on, every sweep is stored, until a new ERASE/PREP cycle is issued, by the AUTO ERASE timer or by the front panel push button.



Variable persistence

Obviously, I was curious also about the other modes. I was somewhat surprised seeing that the **Variable Persistence** mode is almost identical to the Bistable mode, only with a different **recipe** of voltages on the various electrodes (I don't report here the timing diagram, that you can find in the manual).

So I went to read again what I wrote in the 7000-Series e-book where I presented, for the bistable mode, a simpler CRT model than the one here described (e.g., it has the Collector in addition).

I guess that, in this case, like for the other CRT storage scopes, Tektronix wanted just to offer a Bistable mode, in addition to the others, probably only for its capability to store images for a longer time, but with a tube designed to operate mainly in Variable Persistence mode.

Fast modes

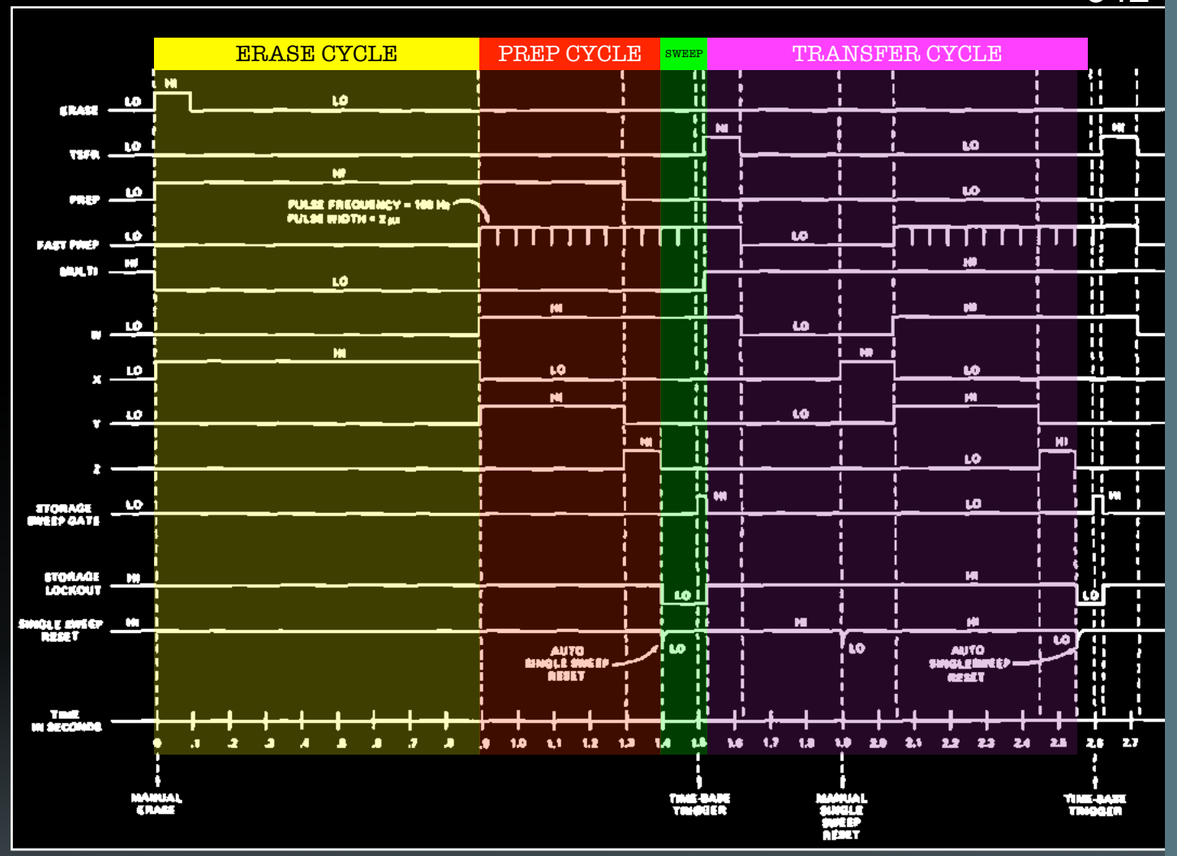
Things become more interesting with the **Fast modes**, where I can find confirmations of what I imagined. In them, the timing diagram become more complex, because the storage operation is performed in more stages: in the first the CRT is erased (yellow in the picture); in the second it is prepared for to store the waveform on the Fast Mesh (red), and, when all is ready (STORAGE LOCKOUT = 0), the sweep can take place (green). But in this way, we only stored the image on the Fast Mesh, currently our wax tablet. An extra cycle is required to transfer the image from the Fast to the Front Mesh.

Conclusions

We have briefly reviewed the problems related to the CRT storage system. Summarizing:

- check all the scope voltages, they must be OK, like blood analyses before doing more complex exams;
- calibrate the CRT / Z-Axis section as prescribed by the manual;
- check that all the static voltages are those prescribed by the manual for each operating mode. It requires some time, but is easy and just a high-impedance VOM is required;
- check the prescribed waveforms as well, they are just a few;
- follow very, very carefully the calibration instructions.

The results can be very interesting. I showed you in the beginning of this chapter, a capture of a single shot 350-MHz waveform, far beyond the declared specifications (which corresponds, for the Reduced Scan Fast Variable Persistence mode, to 275 MHz). If you keep the rule of 10 points for a waveform cycle, it should be equivalent to a 3.5 GHz Digital Storage Oscilloscope.



Save Your Fingers

In the 7834, almost all the storage test points are positioned in such a way that you can be sure that during the calibration you lose a finger during the calibration, or at least the probes of your test oscilloscope.

So, it is advisable that you disconnect the fan before going around the threatening propeller… Working in free air, I had no problem with the temperature.

